FREE

SYSTEM DESIGN

THE BIG ARCHIVE

MAY-17-2022

ByteByteGo

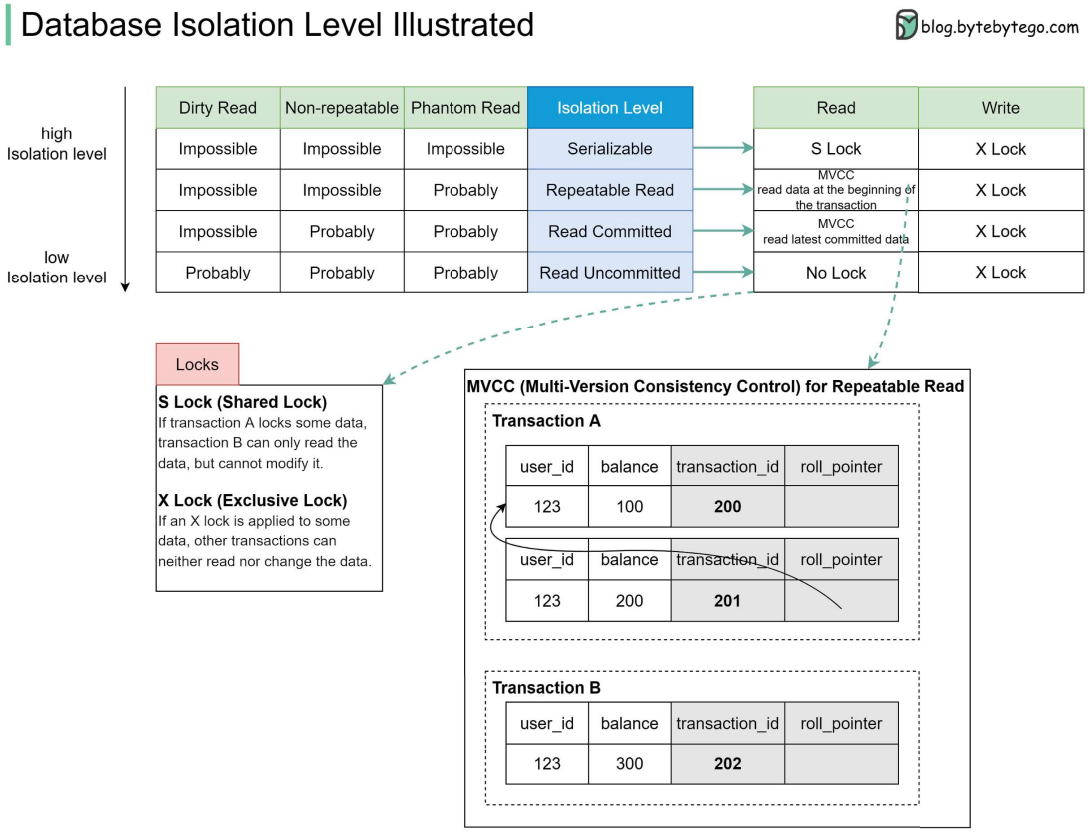
By ByteByteGo.com

System Design

What are database isolation levels? What are they used for?

Database isolation allows a transaction to execute as if there are no other concurrently running transactions.

The diagram below illustrates four isolation levels.



🔹 Serializalble: This is the highest isolation level. Concurrent transactions are guaranteed to be executed in sequence.

🔹 Repeatable Read: Data read during the transaction stays the same as the transaction starts.

🔹 Read Committed: Data modification can only be read after the transaction is committed.

🔹 Read Uncommitted: The data modification can be read by other transactions before a transaction is committed.

The isolation is guaranteed by MVCC (Multi-Version Consistency Control) and locks.

The diagram below takes Repeatable Read as an example to demonstrate how MVCC works:

There are two hidden columns for each row: transaction_id and roll_pointer. When transaction A starts, a new Read View with transaction_id=201 is created. Shortly afterward, transaction B starts, and a new Read View with transaction_id=202 is created.

Now transaction A modifies the balance to 200, a new row of the log is created, and the roll_pointer points to the old row. Before transaction A commits, transaction B reads the balance data. Transaction B finds that transaction_id 201 is not committed, it reads the next committed record(transaction_id=200).

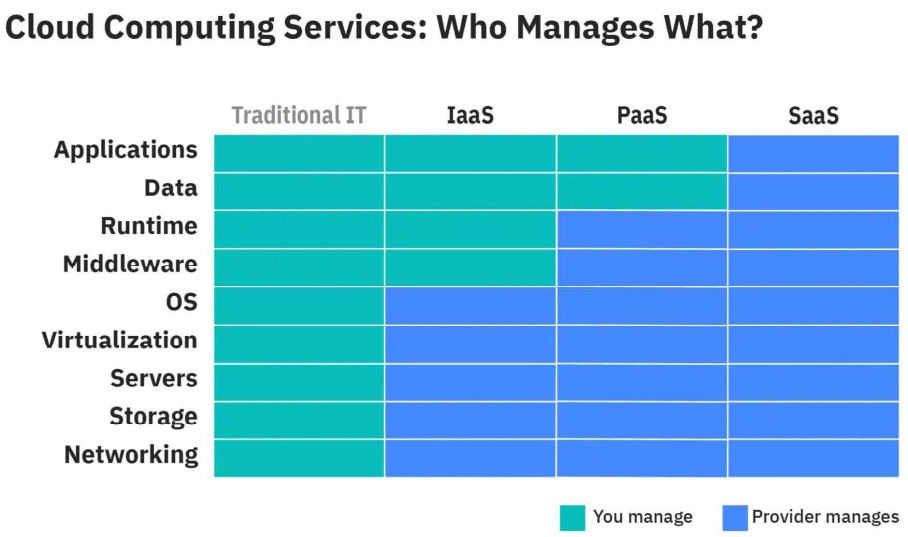
Even when transaction A commits, transaction B still reads data based on the Read View created when transaction B starts. So transaction B always reads the data with balance=100.

Over to you: have you seen isolation levels used in the wrong way? Did it cause serious outages?

—

What is IaaS/PaaS/SaaS?

The diagram below illustrates the differences between IaaS (Infrastructure-as-a-Service), PaaS (Platform-as-a-Service), and SaaS (Software-as-a-Service).



For a non-cloud application, we own and manage all the hardware and software. We say the application is on-premises.

With cloud computing, cloud service vendors provide three kinds of models for us to use: IaaS, PaaS, and SaaS.

IaaS provides us access to cloud vendors' infrastructure, like servers, storage, and networking. We pay for the infrastructure service and install and manage supporting software on it for our application.

PaaS goes further. It provides a platform with a variety of middleware, frameworks, and tools to build our application. We only focus on application development and data.

SaaS enables the application to run in the cloud. We pay a monthly or annual fee to use the SaaS product.

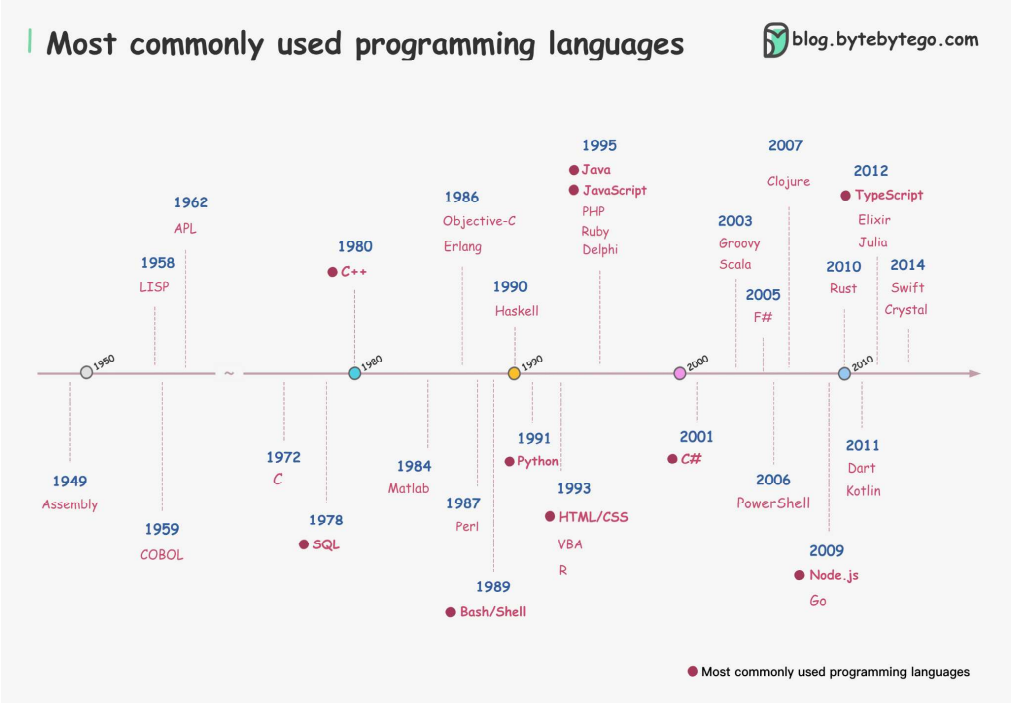
Over to you: which IaaS/PaaS/SaaS products have you used? How do you decide which architecture to use?

Image Source: https://www.ibm.com/cloud/learn/iaas-paas-saas

Most popular programming languages

Programming languages come and go. Some stand the test of time. Some already are shooting stars and some are rising rapidly on the horizon.

I draw a diagram by putting the top 38 most commonly used programming languages in one place, sorted by year. Data source: StackOverflow survey.



1 JavaScript
2 HTML/CSS
3 Python
4 SQL
5 Java
6 Node
7 TypeScript
8 C
9 Bash/Shell
10 C
11 PHP

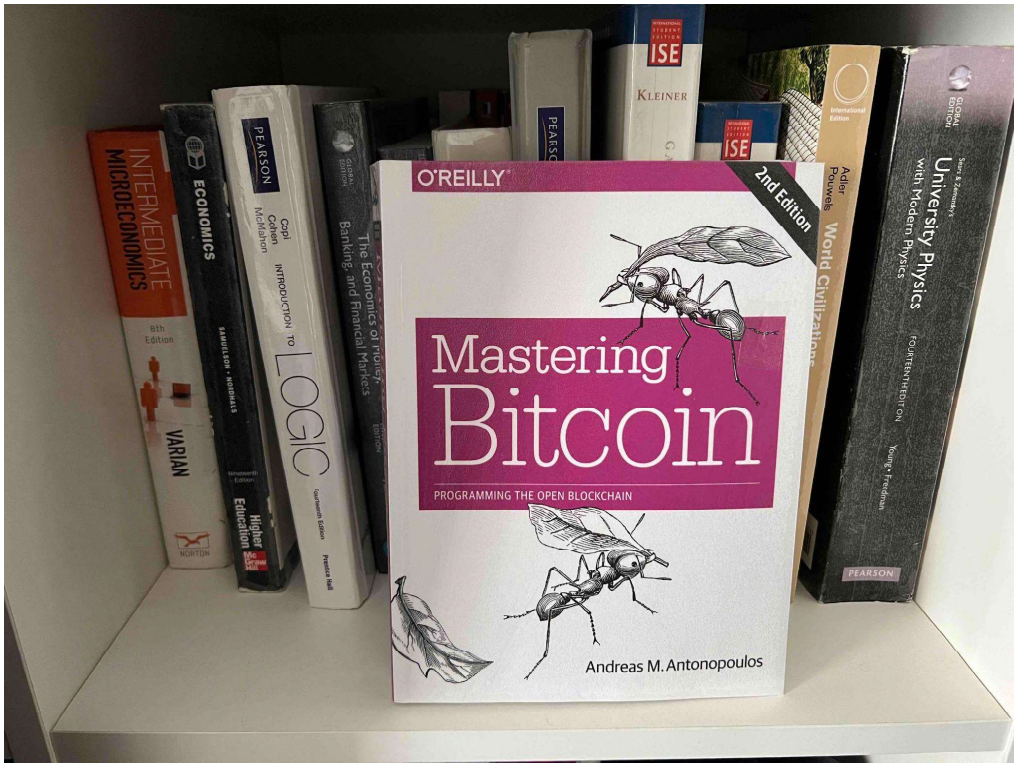
12 C
13 PowerShell
14 Go
15 Kotlin
16 Rust
17 Ruby
18 Dart
19 Assembly
20 Swift
21 R
22 VBA
23 Matlab
24 Groovy
25 Objective-C
26 Scala
27 Perl
28 Haskell
29 Delphi
30 Clojure
31 Elixir
32 LISP
33 Julia
34 F
35 Erlang
36 APL
37 Crystal
38 COBOL

Over to you: what's the first programming language you learned? And what are the other languages you learned over the years?

What is the future of online payments?

I don't know the answer, but I do know one of the candidates is the blockchain.

As a fan of technology, I always seek new solutions to old challenges. A book that explains a lot about an emerging payment system is 'Mastering Bitcoin' by Andreas M. Antonopoulos. I want to share my discovery of this book with you because it explains very clearly bitcoin and its underlying blockchain. This book makes me rethink how to renovate payment systems.



Here are the takeaways:

1. The bitcoin wallet balance is calculated on the fly, while the traditional wallet balance is stored in the database. You can check chapter 12 of System Design Interview Volume 2, on how to implement a traditional wallet (https://amzn.to/34G2vmC).

2. The golden source of truth for bitcoin is the blockchain, which is also the journal. It's the same if we use Event Sourcing architecture to build a traditional wallet, although there are other options.

3. There is a small virtual machine for bitcoin - and also Ethereum. The virtual machine defines a set of bytecodes to do basic tasks such as validation.

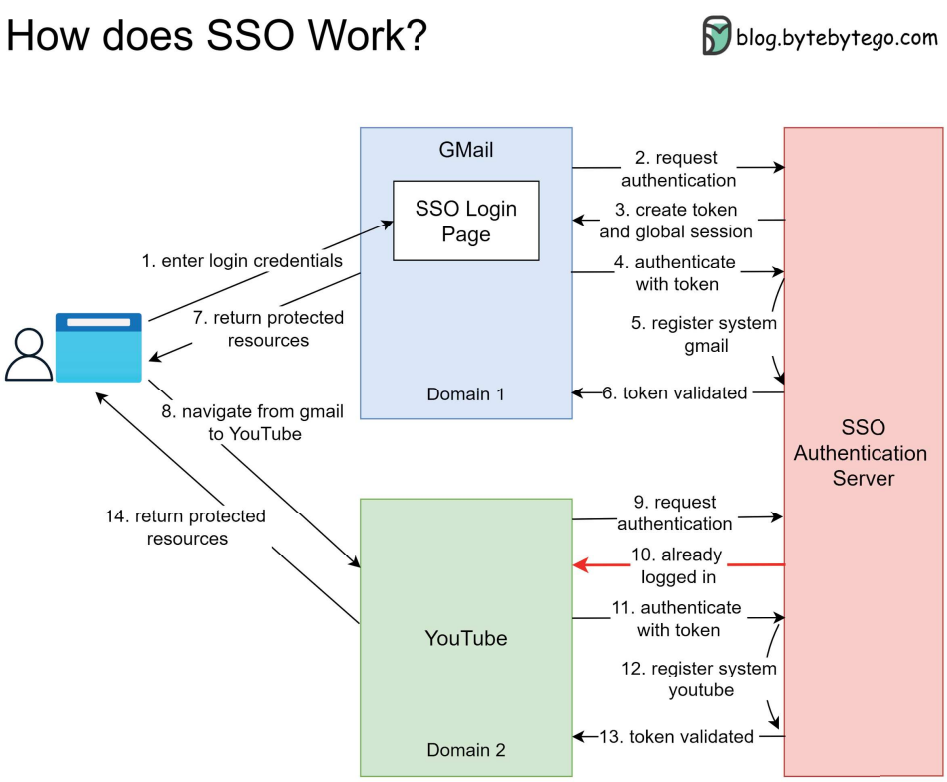
Over to you: if Elon Musk set up a base on planet Mars, what payment solution will you recommend?

What is SSO (Single Sign-On)?

A friend recently went through the irksome experience of being signed out from a number of websites they use daily. This event will be familiar to millions of web users, and it is a tedious process to fix. It can involve trying to remember multiple long-forgotten passwords, or typing in the names of pets from childhood to answer security questions. SSO removes this inconvenience and makes life online better. But how does it work?

Basically, Single Sign-On (SSO) is an authentication scheme. It allows a user to log in to different systems using a single ID.

The diagram below illustrates how SSO works.



Step 1: A user visits Gmail, or any email service. Gmail finds the user is not logged in and so redirects them to the SSO authentication server, which also finds the user is not logged in. As a result, the user

is redirected to the SSO login page, where they enter their login credentials.

Steps 2-3: The SSO authentication server validates the credentials, creates the global session for the user, and creates a token.

Steps 4-7: Gmail validates the token in the SSO authentication server. The authentication server registers the Gmail system, and returns "valid." Gmail returns the protected resource to the user.

Step 8: From Gmail, the user navigates to another Google-owned website, for example, YouTube.

Steps 9-10: YouTube finds the user is not logged in, and then requests authentication. The SSO authentication server finds the user is already logged in and returns the token.

Step 11-14: YouTube validates the token in the SSO authentication server. The authentication server registers the YouTube system, and returns "valid." YouTube returns the protected resource to the user.

The process is complete and the user gets back access to their account.

Over to you:

Question 1: have you implemented SSO in your projects? What is the most difficult part?

Question 2: what's your favorite sign-in method and why?

—

How to store passwords safely in the database?

Let's take a look.

Things NOT to do

- Storing passwords in plain text is not a good idea because anyone with internal access can see them.

- Storing password hashes directly is not sufficient because it is pruned to precomputation attacks, such as rainbow tables.

- To mitigate precomputation attacks, we salt the passwords.

What is salt?

According to OWASP guidelines, "a salt is a unique, randomly generated string that is added to each password as part of the hashing process".

How to store passwords in DB?

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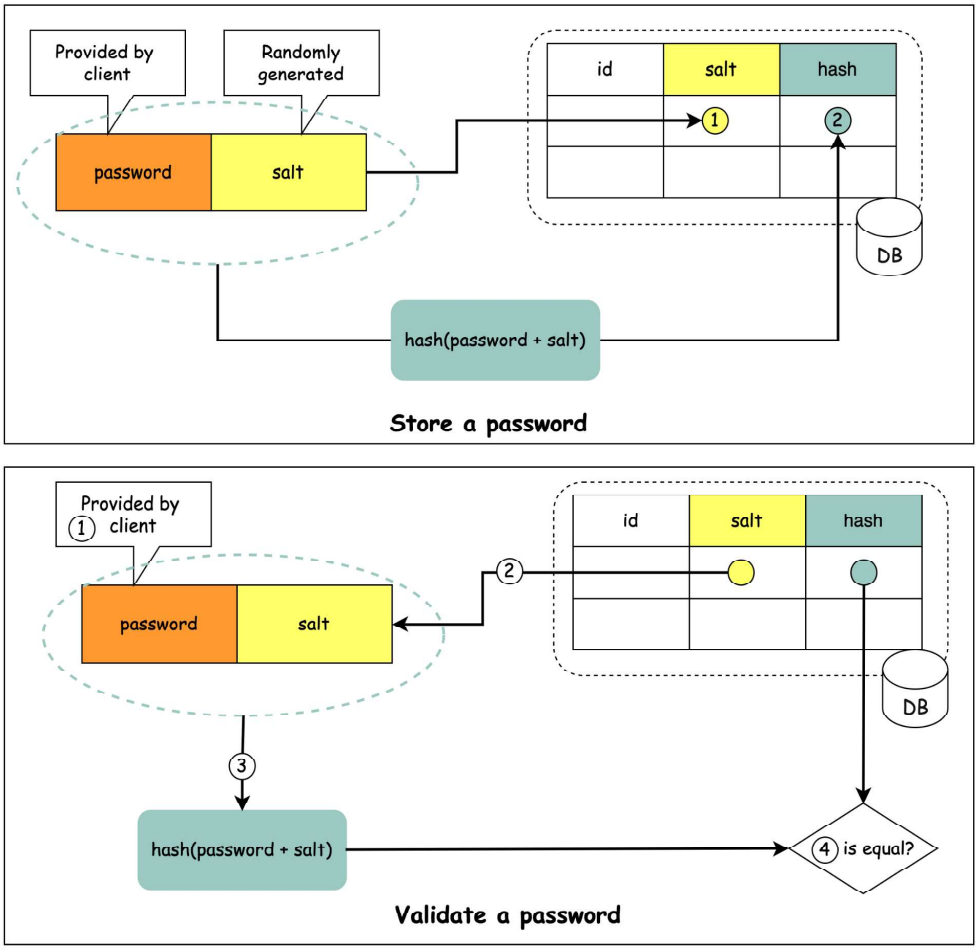

How to store a password and salt?

1 A salt is not meant to be secret and it can be stored in plain text in the database. It is used to ensure the hash result is unique to each password.

2 The password can be stored in the database using the following format: *hash*(*password* + *salt*).

How to validate a password?

To validate a password, it can go through the following process:

1 A client enters the password.

2 The system fetches the corresponding salt from the database.

3️⃣ The system appends the salt to the password and hashes it. Let's call the hashed value H1.
4️⃣ The system compares H1 and H2, where H2 is the hash stored in the database. If they are the same, the password is valid.

Over to you: what other mechanisms can we use to ensure password safety?

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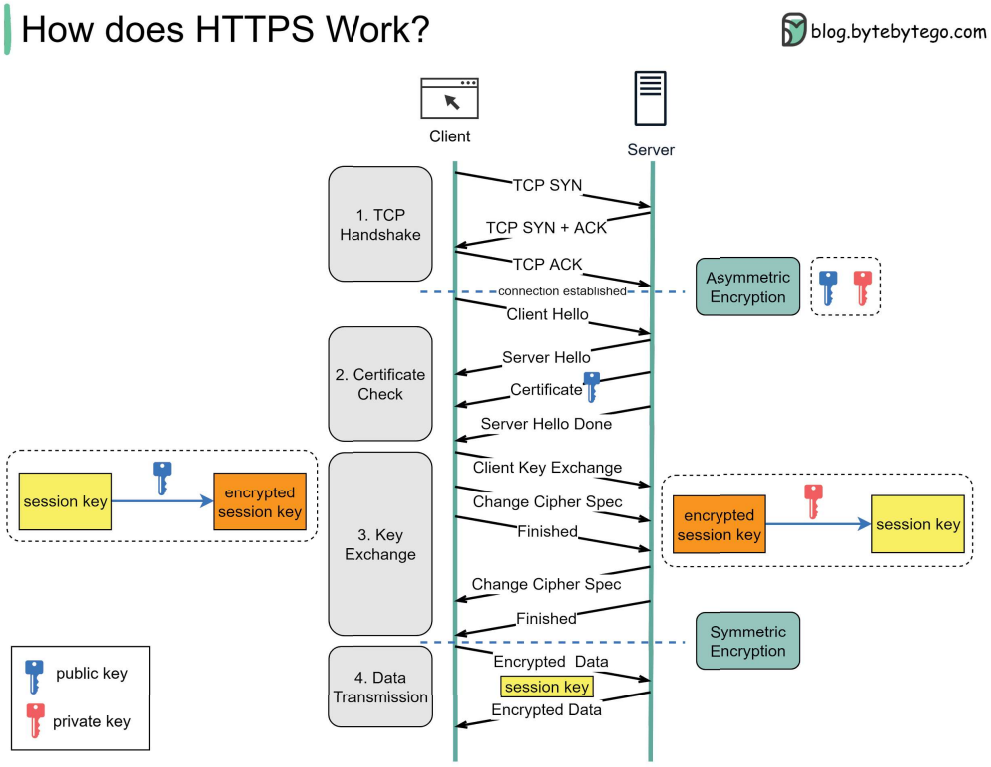
How does HTTPS work?

Hypertext Transfer Protocol Secure (HTTPS) is an extension of the Hypertext Transfer Protocol (HTTP.) HTTPS transmits encrypted data using Transport Layer Security (TLS.) If the data is hijacked online, all the hijacker gets is binary code.



How is the data encrypted and decrypted?

Step 1 - The client (browser) and the server establish a TCP connection.

Step 2 - The client sends a “client hello” to the server. The message contains a set of necessary encryption algorithms (cipher suites) and the latest TLS version it can support. The server responds with a “server hello” so the browser knows whether it can support the algorithms and TLS version.

The server then sends the SSL certificate to the client. The certificate contains the public key, host name, expiry dates, etc. The client validates the certificate.

Step 3 - After validating the SSL certificate, the client generates a session key and encrypts it using the public key. The server receives the encrypted session key and decrypts it with the private key.

Step 4 - Now that both the client and the server hold the same session key (symmetric encryption), the encrypted data is transmitted in a secure bi-directional channel.

Why does HTTPS switch to symmetric encryption during data transmission? There are two main reasons:

1. Security: The asymmetric encryption goes only one way. This means that if the server tries to send the encrypted data back to the client, anyone can decrypt the data using the public key.

2. Server resources: The asymmetric encryption adds quite a lot of mathematical overhead. It is not suitable for data transmissions in long sessions.

Over to you: how much performance overhead does HTTPS add, compared to HTTP?

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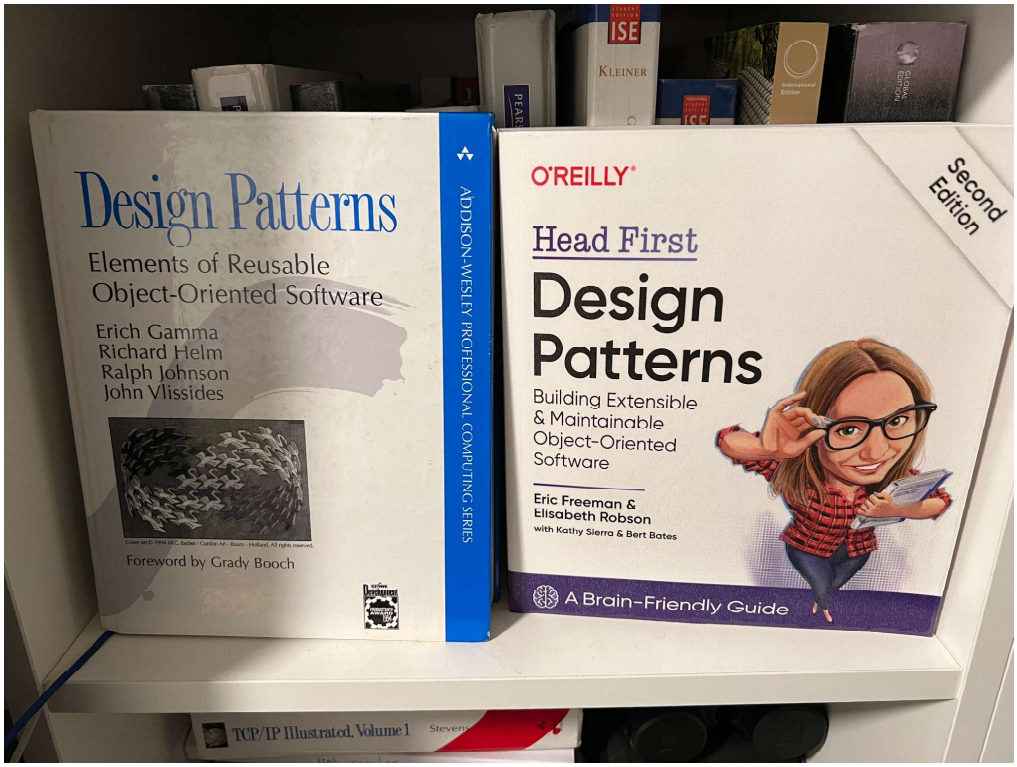
How to learn design patterns?

Besides reading a lot of well-written code, a good book guides us like a good teacher.

Head First Design Patterns, second edition, is the one I would recommend.



When I began my journey in software engineering, I found it hard to understand the classic textbook, **Design Patterns,** by the Gang of Four. Luckily, I discovered Head First Design Patterns in the school library. This book solved a lot of puzzles for me. When I went back to the Design Patterns book, everything looked familiar and more understandable.

Last year, I bought the second edition of Head First Design Patterns and read through it. Here are a few things I like about the book:

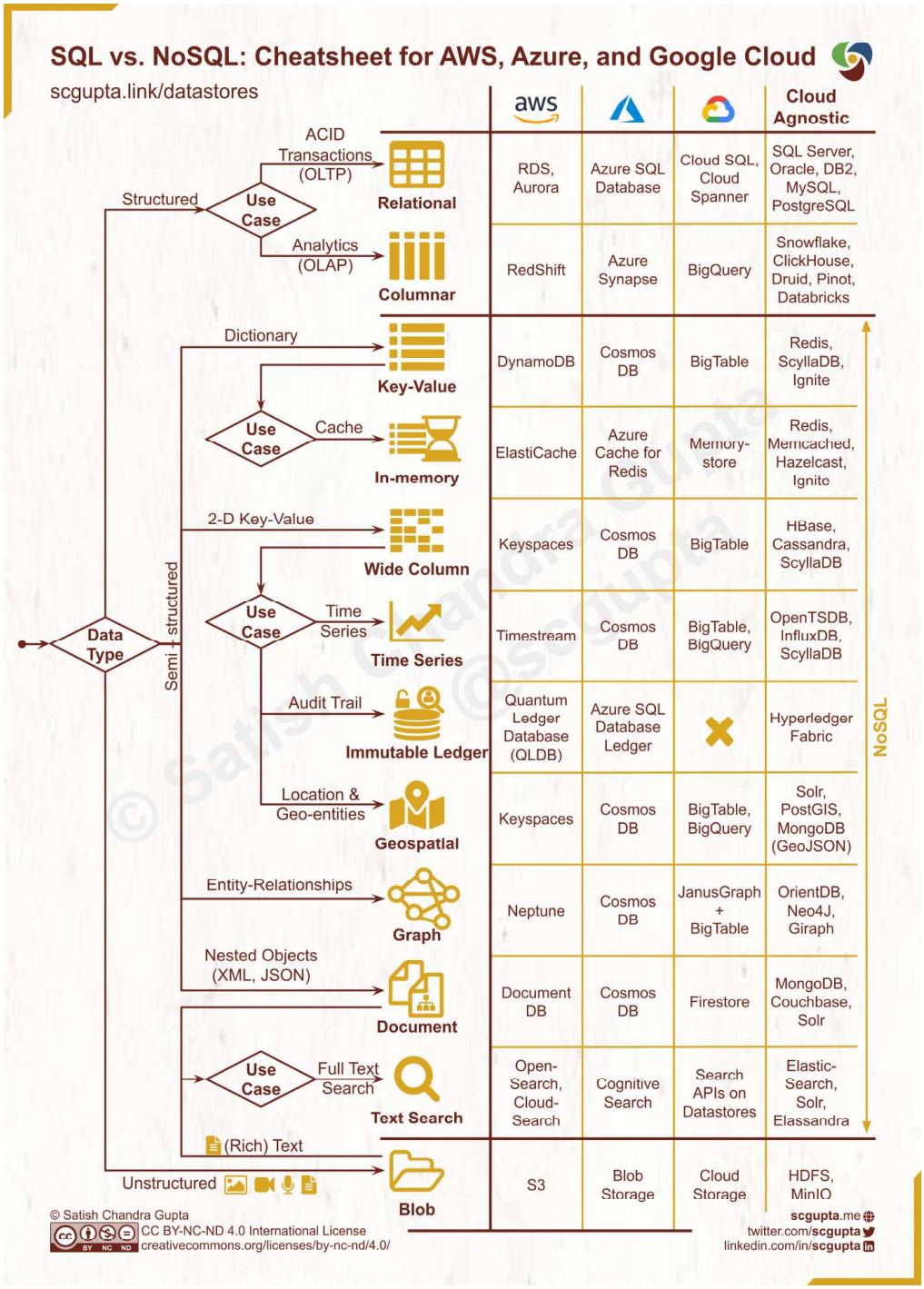
- This book solves the challenge of software's abstract, "invisible" nature. Software is difficult to build because we cannot see its architecture; its details are embedded in the code and binary files. It is even harder to understand software design patterns because these are higher-level abstractions of the software. The book fixes this by using visualization. There are lots of diagrams, arrows, and comments on almost every page. If I do not understand the text, it's no problem. The diagrams explain things very well.

- We all have questions we are afraid to ask when we first learn a new skill. Maybe we think it's an easy one. This book is good at tackling design patterns from the student's point of view. It guides us by asking our questions and clearly answering them. There is a Guru in the book and there's also a Student.

Over to you: which book helped you understand a challenging topic? Why do you like it?

A visual guide on how to choose the right Database

Picking a database is a long-term commitment so the decision shouldn't be made lightly. The important thing to keep in mind is to choose the right database for the right job.



Data can be structured (SQL table schema), semi-structured (JSON, XML, etc.), and unstructured (Blob).

Common database categories include:

- Relational
- Columnar
- Key-value
- In-memory
- Wide column
- Time Series
- Immutable ledger
- Geospatial
- Graph
- Document
- Text search
- Blob

Thanks, Satish Chandra Gupta

Over to you - Which database have you used for which workload?

Do you know how to generate globally unique IDs?

In this post, we will explore common requirements for IDs that are used in social media such as Facebook, Twitter, and LinkedIn.

Requirements:

- Globally unique
- Roughly sorted by time
- Numerical values only
- 64 bits
- Highly scalable, low latency

Unique ID Generator

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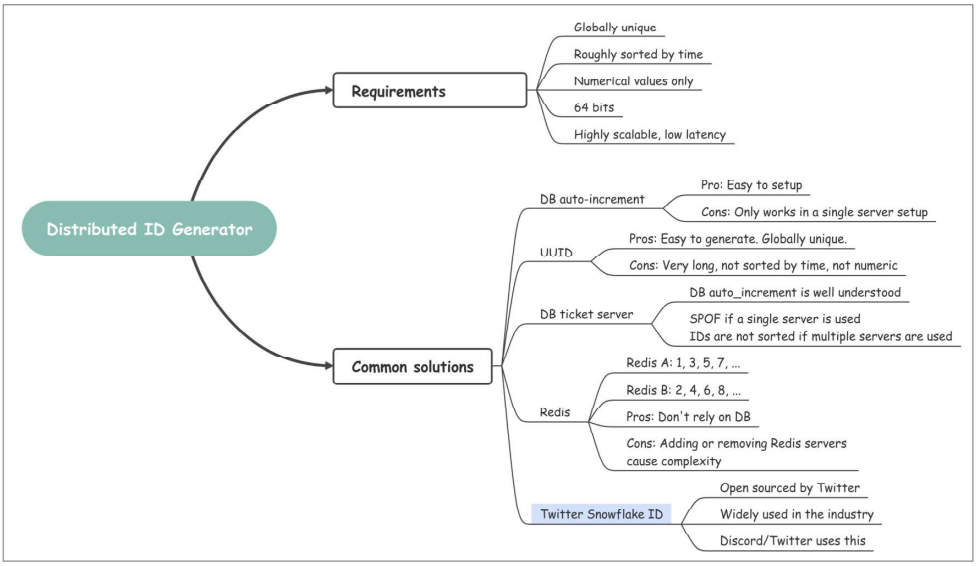
	Reasons
Globally unique	If IDs are not globally unique, there could be collisions.
Roughly sorted by time	So user IDs, post IDs can be sorted by time without fetching additional info
Numerical values only	Naturally sortable by time
64 bits	2^32 = ~4 billion -> not enough IDs. 2^64 is big enough 2^128 wastes space and is too long
Highly scalable, low latency	Ability to generate a lot of IDs per second in low latency fashion is critical.



The implementation details of the algorithms can be found online so we will not go into detail here.

Over to you: What kind of ID generators have you used?

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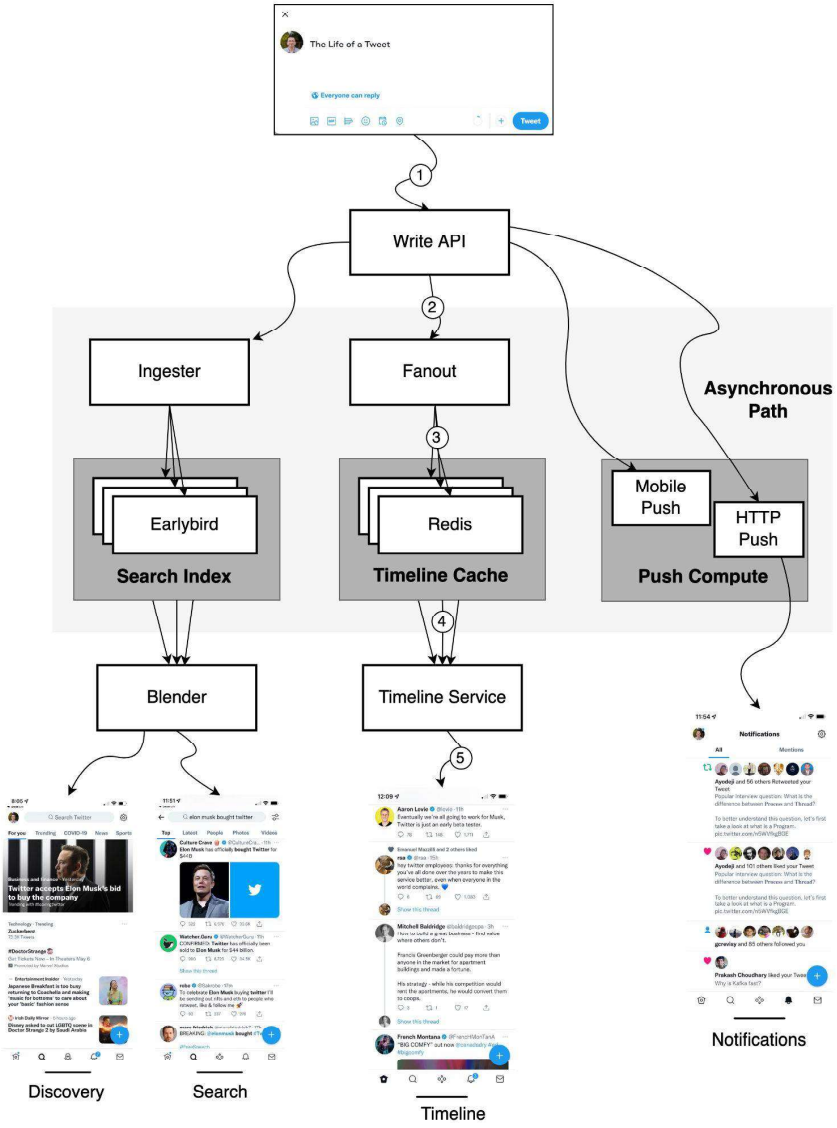
Paperback: Amazon Digital: ByteByteGo.

How does Twitter work?

This post is a summary of a tech talk given by Twitter in 2013. Let's take a look.



The Life of a Tweet:

1. A tweet comes in through the Write API.
2. The Write API routes the request to the Fanout service.
3. The Fanout service does a lot of processing and stores them in the Redis cache.

4️⃣ The Timeline service is used to find the Redis server that has the home timeline on it.
5️⃣ A user pulls their home timeline through the Timeline service.

Search & Discovery

- Ingester: annotates and tokenizes Tweets so the data can be indexed.
- Earlybird: stores search index.
- Blender: creates the search and discovery timelines.

Push Compute

- HTTP push
- Mobile push

Disclaimer: This article is based on the tech talk given by Twitter in 2013 (https://bit.ly/3vNfjRp). Even though many years have passed, it's still quite relevant. I redraw the diagram as the original diagram is difficult to read.

Over to you:
Do you use Twitter? What are some of the biggest differences between LinkedIn and Twitter that might shape their system architectures?

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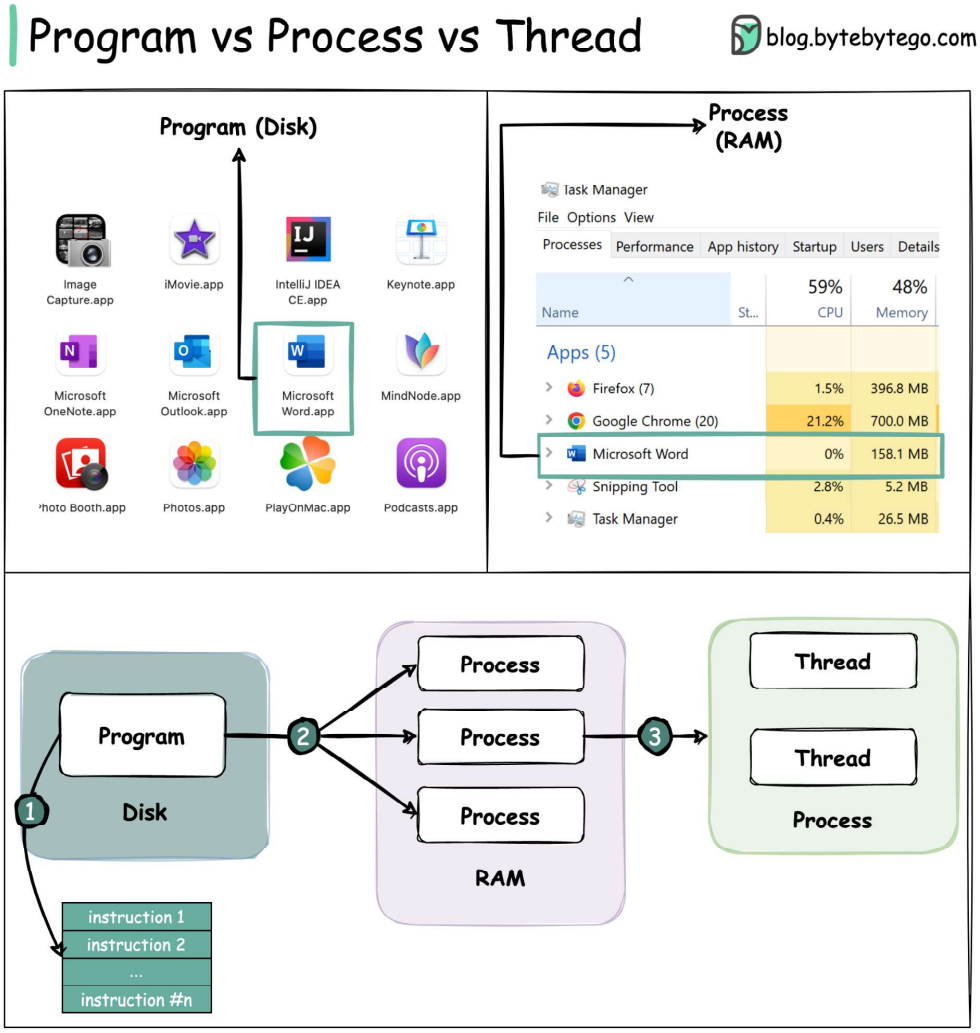
What is the difference between Process and Thread?



To better understand this question, let's first take a look at what is a Program. A **Program** is an executable file containing a set of instructions and passively stored on disk. One program can have multiple processes. For example, the Chrome browser creates a different process for every single tab.

A **Process** means a program is in execution. When a program is loaded into the memory and becomes active, the program becomes a process. The process requires some essential resources such as registers, program counter, and stack.

A **Thread** is the smallest unit of execution within a process.

The following process explains the relationship between program, process, and thread.

1. The program contains a set of instructions.
2. The program is loaded into memory. It becomes one or more running processes.
3. When a process starts, it is assigned memory and resources. A process can have one or more threads. For example, in the Microsoft Word app, a thread might be responsible for spelling checking and the other thread for inserting text into the doc.

Main differences between process and thread:

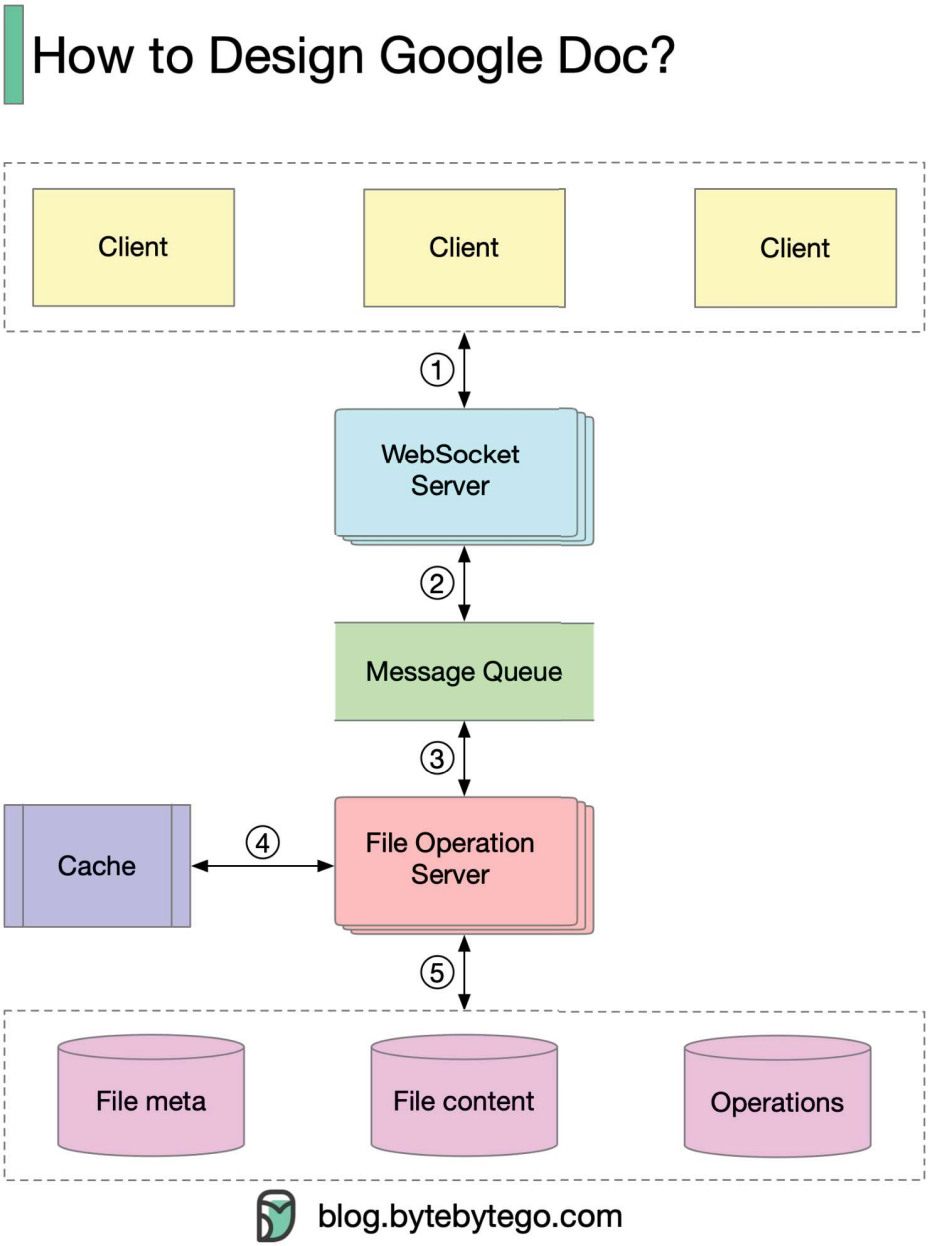
- Processes are usually independent, while threads exist as subsets of a process.
- Each process has its own memory space. Threads that belong to the same process share the same memory.
- A process is a heavyweight operation. It takes more time to create and terminate.
- Context switching is more expensive between processes.
- Inter-thread communication is faster for threads.

Over to you:
1). Some programming languages support coroutine. What is the difference between coroutine and thread?

2). How to list running processes in Linux?

—

Interview Question: design Google Docs



1 Clients send document editing operations to the WebSocket Server.
2 The real-time communication is handled by the WebSocket Server.
3 Documents operations are persisted in the Message Queue.

4️⃣ The File Operation Server consumes operations produced by clients and generates transformed operations using collaboration algorithms.
5️⃣ Three types of data are stored: file metadata, file content, and operations.

One of the biggest challenges is real-time conflict resolution. Common algorithms include:

- Operational transformation (OT)
- Differential Synchronization (DS)
- Conflict-free replicated data type (CRDT)

Google Doc uses OT according to its Wikipedia page and CRDT is an active area of research for real-time concurrent editing.

Over to you - Have you encountered any issues while using Google Docs? If so, what do you think might have caused the issue?

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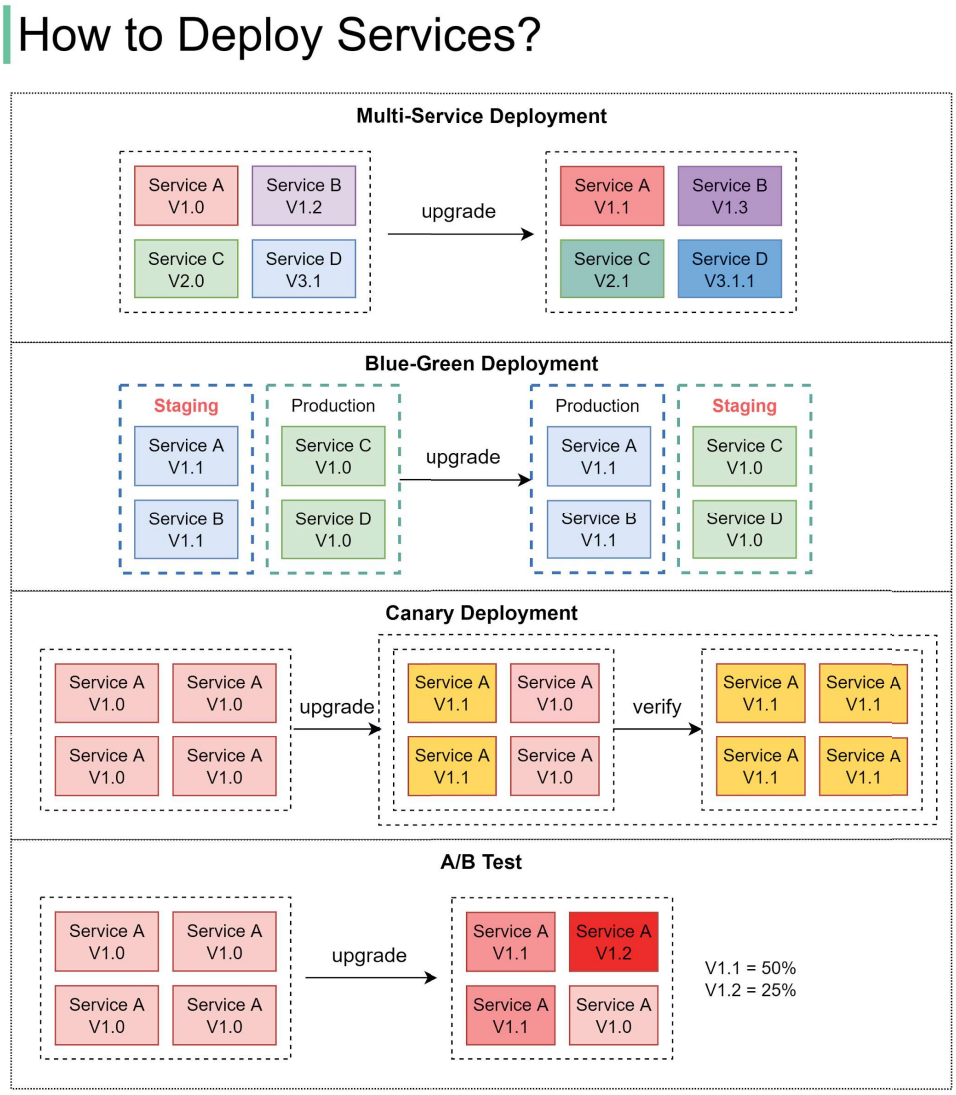
Deployment strategies

Deploying or upgrading services is risky. In this post, we explore risk mitigation strategies.

The diagram below illustrates the common ones.



Multi-Service Deployment

In this model, we deploy new changes to multiple services simultaneously. This approach is easy to implement. But since all the services are upgraded at the same time, it is hard to manage and test dependencies. It's also hard to rollback safely.

Blue-Green Deployment

With blue-green deployment, we have two identical environments: one is staging (blue) and the other is production (green). The staging environment is one version ahead of production. Once testing is done in the staging environment, user traffic is switched to the staging environment, and the staging becomes the production. This deployment strategy is simple to perform rollback, but having two identical production quality environments could be expensive.

Canary Deployment

A canary deployment upgrades services gradually, each time to a subset of users. It is cheaper than blue-green deployment and easy to perform rollback. However, since there is no staging environment, we have to test on production. This process is more complicated because we need to monitor the canary while gradually migrating more and more users away from the old version.

A/B Test

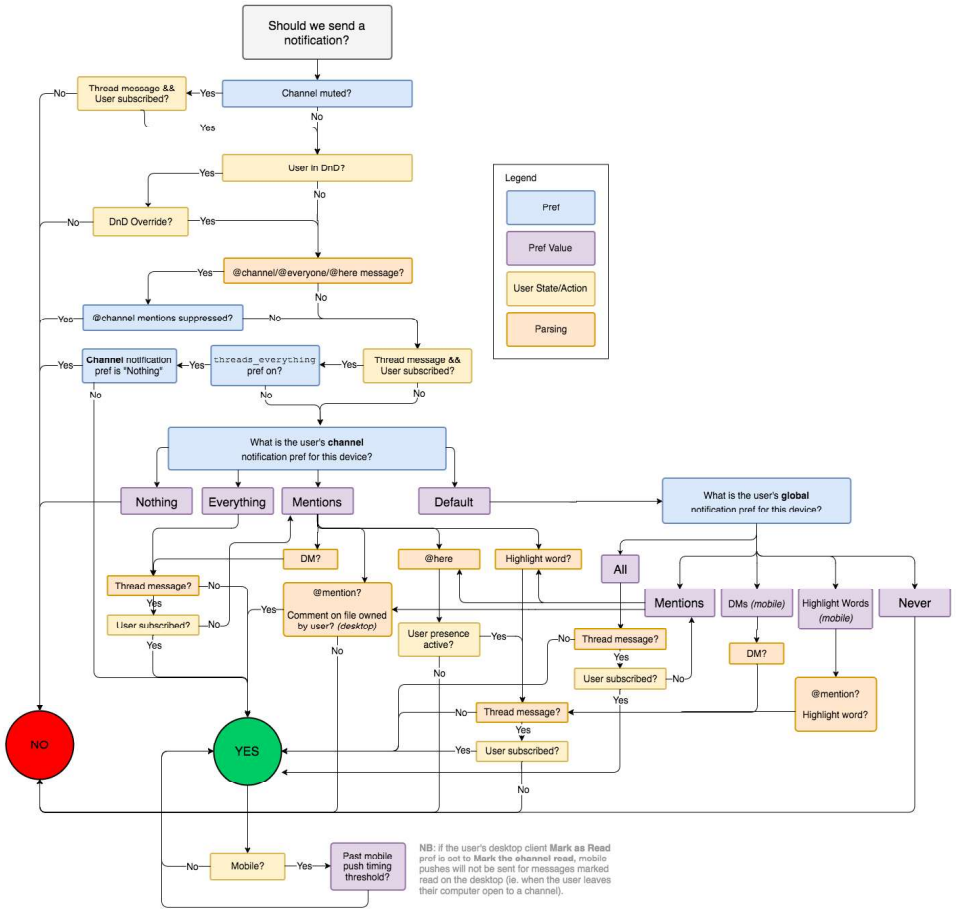
In the A/B test, different versions of services run in production simultaneously. Each version runs an “experiment” for a subset of users. A/B test is a cheap method to test new features in production. We need to control the deployment process in case some features are pushed to users by accident.

Over to you - Which deployment strategy have you used? Did you witness any deployment-related outages in production and why did they happen?

Flowchart of how slack decides to send a notification

It is a great example of why a simple feature may take much longer to develop than many people think.

When we have a great design, users may not notice the complexity because it feels like the feature is just working as intended.

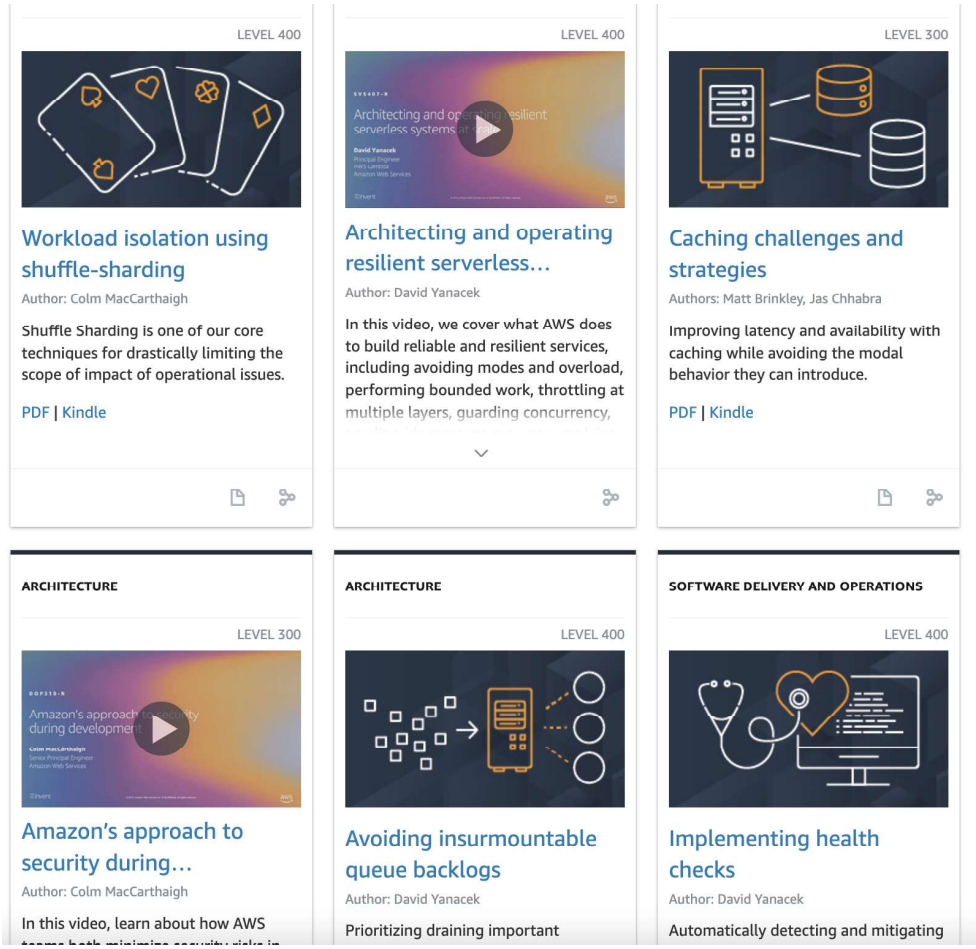


What's your takeaway from this diagram?

Image source:
https://slack.engineering/reducing-slacks-memory-footprint/

How does Amazon build and operate the software?

In 2019, Amazon released The Amazon Builders' Library. It contains architecture-based articles that describe how Amazon architects, releases, and operates technology.



As of today, it published 26 articles. It took me two weekends to go through all the articles. I've had great fun and learned a lot. Here are some of my favorites:

- Making retries safe with idempotent APIs
- Timeouts, retries, and backoff with jitter
- Beyond five 9s: Lessons from our highest available data planes
- Caching challenges and strategies
- Ensuring rollback safety during deployments
- Going faster with continuous delivery

- Challenges with distributed systems
- Amazon's approach to high-availability deployment

Over to you: what's your favorite place to learn system design and design principles?

Link to The Amazon Builders' Library: aws.amazon.com/builders-library

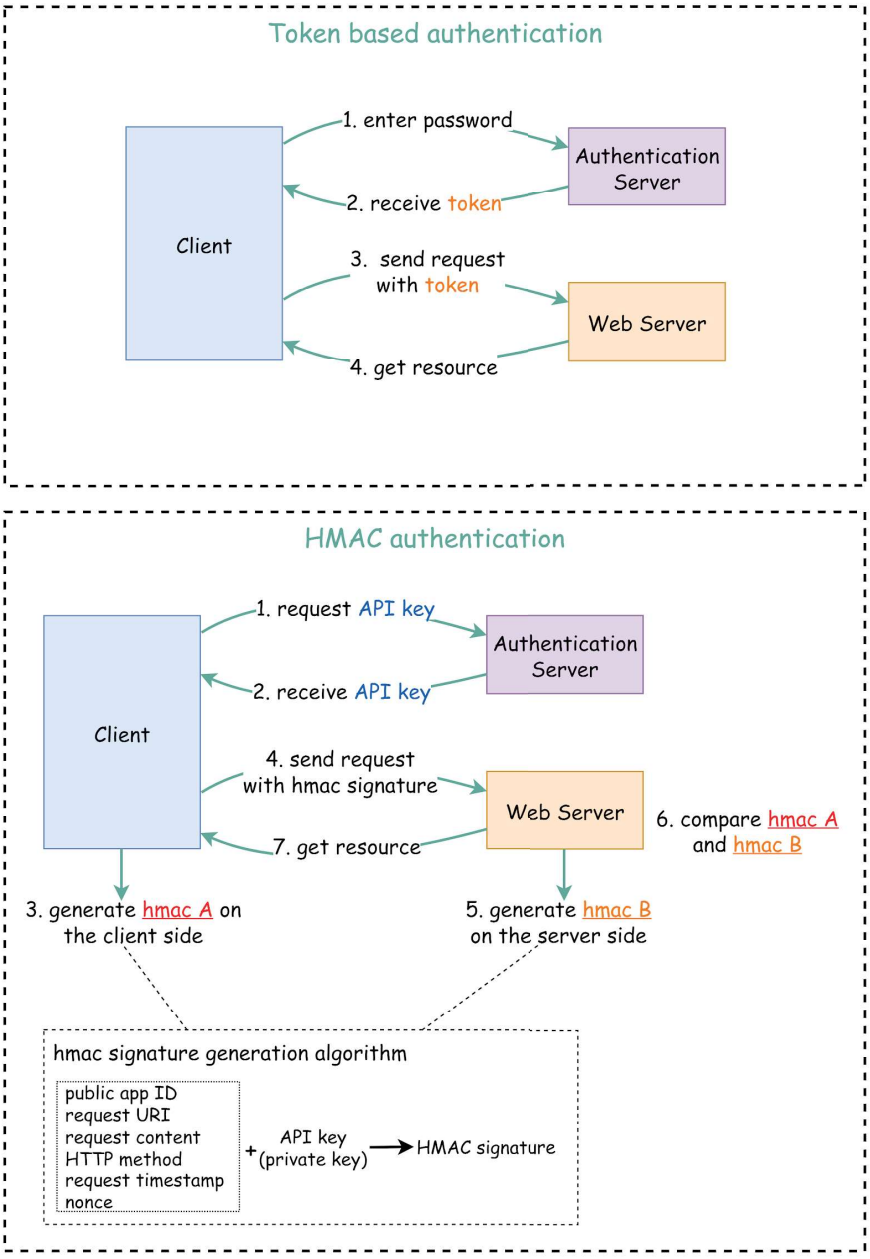
How to design a secure web API access for your website?

When we open web API access to users, we need to make sure each API call is authenticated. This means the user must be who they claim to be.

In this post, we explore two common ways:
1. Token based authentication
2. HMAC (Hash-based Message Authentication Code) authentication

The diagram below illustrates how they work.

How to Design Secure Web API?



Token based

Step 1 - the user enters their password into the client, and the client sends the password to the Authentication Server.

Step 2 - the Authentication Server authenticates the credentials and generates a token with an expiry time.

Steps 3 and 4 - now the client can send requests to access server resources with the token in the HTTP header. This access is valid until the token expires.

HMAC based

This mechanism generates a Message Authentication Code (signature) by using a hash function (SHA256 or MD5).

Steps 1 and 2 - the server generates two keys, one is Public APP ID (public key) and the other one is API Key (private key).
Step 3 - we now generate a HMAC signature on the client side (hmac A). This signature is generated with a set of attributes listed in the diagram.

Step 4 - the client sends requests to access server resources with hmac A in the HTTP header.

Step 5 - the server receives the request which contains the request data and the authentication header. It extracts the necessary attributes from the request and uses the API key that's stored on the server side to generate a signature (hmac B.)

Steps 6 and 7 - the server compares hmac A (generated on the client side) and hmac B (generated on the server side). If they are matched, the requested resource will be returned to the client.

Question - How does HMAC authentication ensure data integrity? Why do we include "request timestamp" in HMAC signature generation?

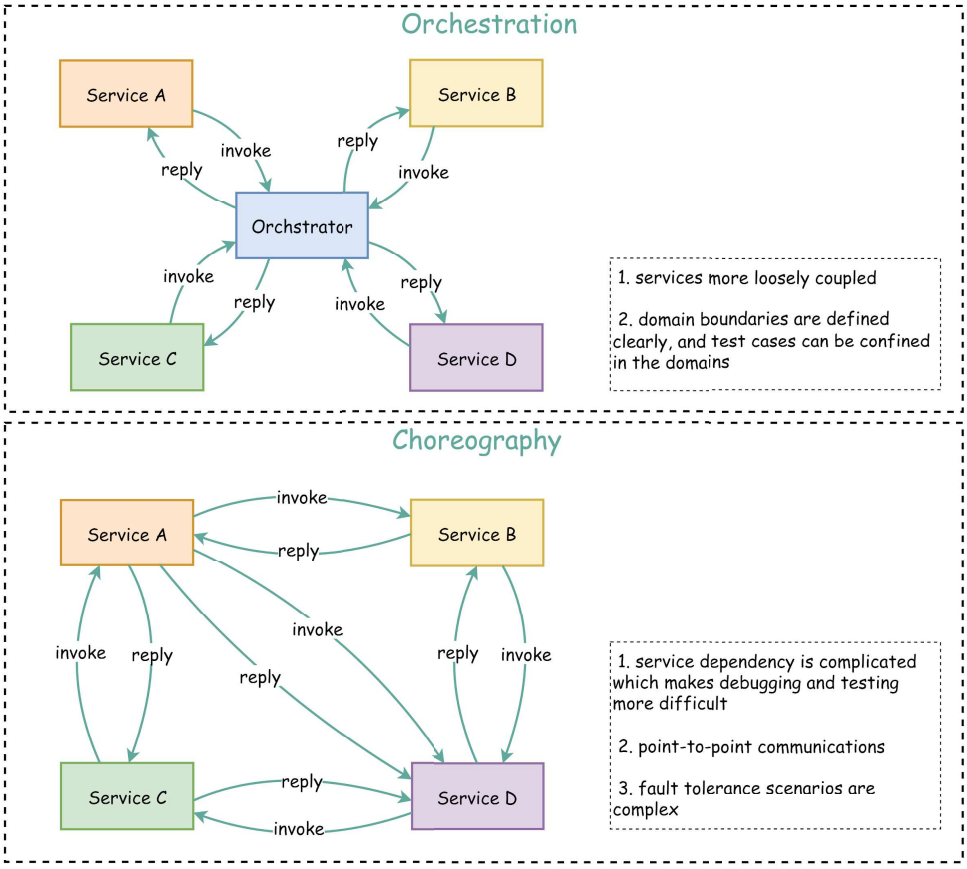
—

How do microservices collaborate and interact with each other?

There are two ways: **orchestration** and **choreography**.

The diagram below illustrates the collaboration of microservices.

> Orchestration v.s. Choreography of Microservices



Choreography is like having a choreographer set all the rules. Then the dancers on stage (the microservices) interact according to them. Service choreography describes this exchange of messages and the rules by which the microservices interact.

Orchestration is different. The orchestrator acts as a center of authority. It is responsible for invoking and combining the services. It

describes the interactions between all the participating services. It is just like a conductor leading the musicians in a musical symphony. The orchestration pattern also includes the transaction management among different services.

The benefits of orchestration:
1. Reliability - orchestration has built-in transaction management and error handling, while choreography is point-to-point communications and the fault tolerance scenarios are much more complicated.
2. Scalability - when adding a new service into orchestration, only the orchestrator needs to modify the interaction rules, while in choreography all the interacting services need to be modified.

Some limitations of orchestration:
1. Performance - all the services talk via a centralized orchestrator, so latency is higher than it is with choreography. Also, the throughput is bound to the capacity of the orchestrator.
2. Single point of failure - if the orchestrator goes down, no services can talk to each other. To mitigate this, the orchestrator must be highly available.

Real-world use case: Netflix Conductor is a microservice orchestrator and you can read more details on the orchestrator design.

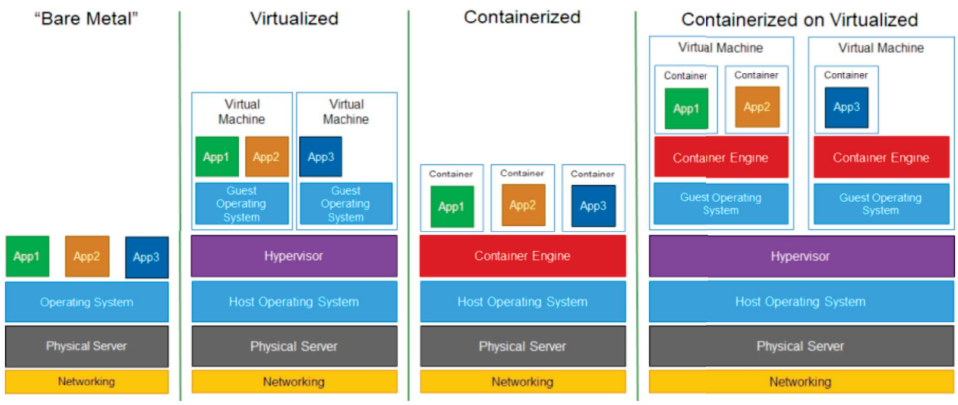
Question - Have you used orchestrator products in production? What are their pros & cons?

—

What are the differences between Virtualization (VMware) and Containerization (Docker)?

The diagram below illustrates the layered architecture of virtualization and containerization.

Virtualization vs Containerization



"Virtualization is a technology that allows you to create multiple simulated environments or dedicated resources from a single, physical hardware system" [1].

"Containerization is the packaging together of software code with all its necessary components like libraries, frameworks, and other dependencies so that they are isolated in their own "container" [2].

The major differences are:

- In virtualization, the hypervisor creates an abstraction layer over hardware, so that multiple operating systems can run alongside each other. This technique is considered to be the first generation of cloud computing.

- Containerization is considered to be a lightweight version of virtualization, which virtualizes the operating system instead of hardware. Without the hypervisor, the containers enjoy faster resource provisioning. All the resources (including code, dependencies) that are

needed to run the application or microservice are packaged together, so that the applications can run anywhere.

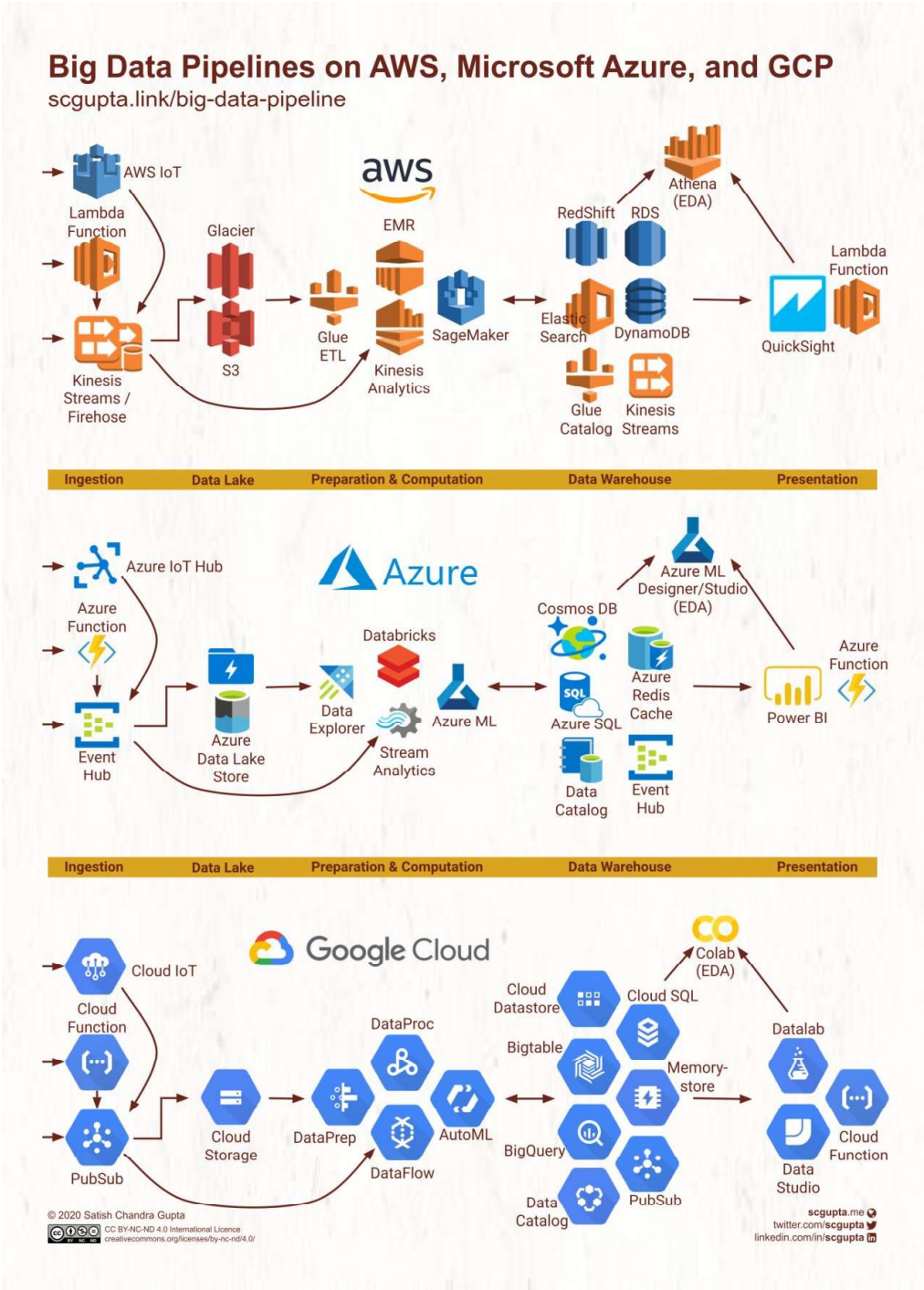
Question: how much performance differences have you observed in production between virtualization, containerization, and bare-metal?

Image Source: https://lnkd.in/gaPYcGTz

Sources:
[1] Understanding virtualization: https://lnkd.in/gtQY9gkx
[2] What is containerization?: https://lnkd.in/gm4Qv_x2

Which cloud provider should be used when building a big data solution?

The diagram below illustrates the detailed comparison of AWS, Google Cloud, and Microsoft Azure.



The common parts of the solutions:

1. Data ingestion of structured or unstructured data.
2. Raw data storage.
3. Data processing, including filtering, transformation, normalization, etc.
4. Data warehouse, including key-value storage, relational database, OLAP database, etc.
5. Presentation layer with dashboards and real-time notifications.

It is interesting to see different cloud vendors have different names for the same type of products.

For example, the first step and the last step both use the serverless product. The product is called “lambda” in AWS, and “function” in Azure and Google Cloud.

Question - which products have you used in production? What kind of application did you use it for?

Source: S.C. Gupta’s post

How to avoid crawling duplicate URLs at Google scale?

Option 1: Use a Set data structure to check if a URL already exists or not. Set is fast, but it is not space-efficient.

Option 2: Store URLs in a database and check if a new URL is in the database. This can work but the load to the database will be very high.

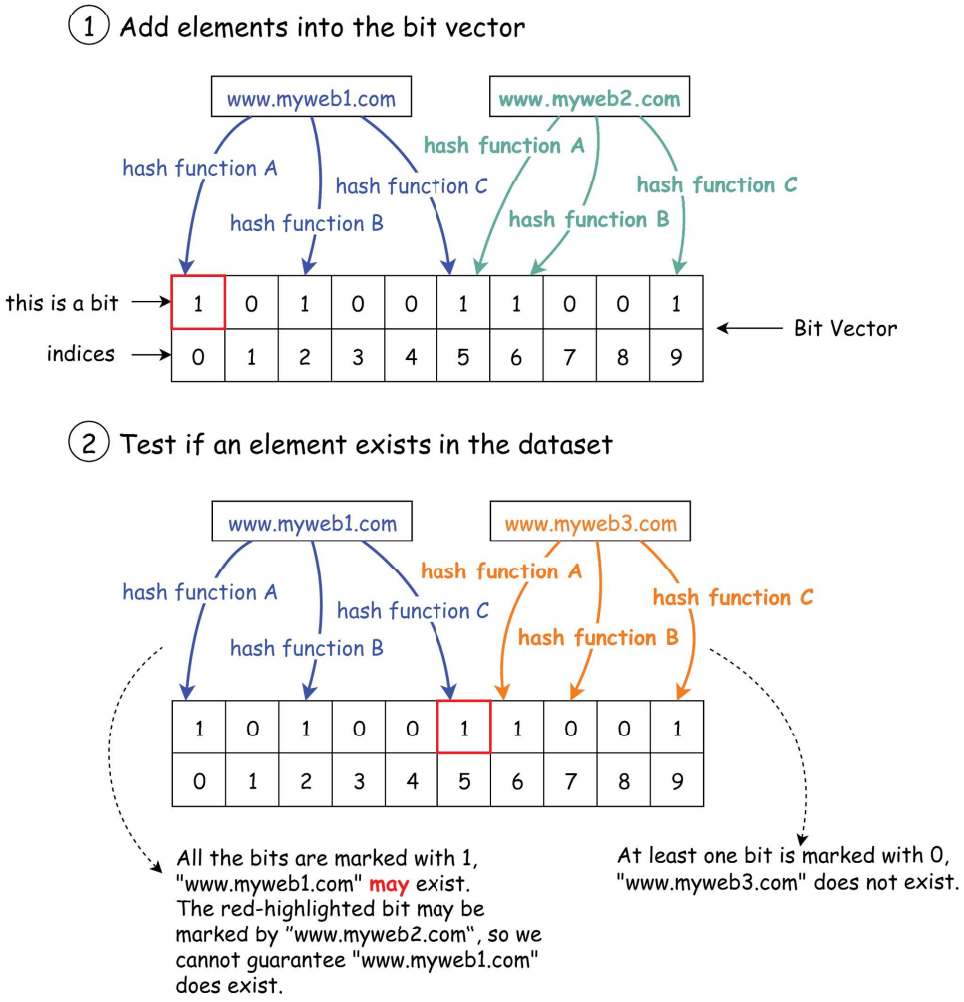
Option 3: **Bloom filter**. This option is preferred. Bloom filter was proposed by Burton Howard Bloom in 1970. It is a probabilistic data structure that is used to test whether an element is a member of a set.

- false: the element is definitely not in the set.
- true: the element is probably in the set.

False-positive matches are possible, but false negatives are not.

The diagram below illustrates how the Bloom filter works. The basic data structure for the Bloom filter is Bit Vector. Each bit represents a hashed value.

How to Dedupe Massive URLs



Step 1: To add an element to the bloom filter, we feed it to 3 different hash functions (A, B, and C) and set the bits at the resulting positions. Note that both “www.myweb1.com” and “www.myweb2.com” mark the same bit with 1 at index 5. False positives are possible because a bit might be set by another element.

Step 2: When testing the existence of a URL string, the same hash functions A, B, and C are applied to the URL string. If all three bits are

1, then the URL may exist in the dataset; if any of the bits is 0, then the URL definitely does not exist in the dataset.

Hash function choices are important. They must be uniformly distributed and fast. For example, RedisBloom and Apache Spark use murmur, and InfluxDB uses xxhash.

Question - In our example, we used three hash functions. How many hash functions should we use in reality? What are the trade-offs?

—

Why is a solid-state drive (SSD) fast?

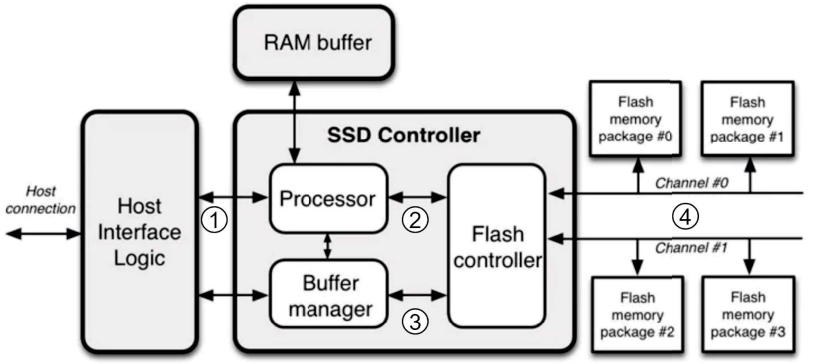
“A solid state drive reads up to 10 times faster and writes up to 20 times faster than a hard disk drive.” [1].

“An SSD is a flash-memory based data storage device. Bits are stored into cells, which are made of floating-gate transistors. SSDs are made entirely of electronic components, there are no moving or mechanical parts like in hard drives (HDD)” [2].

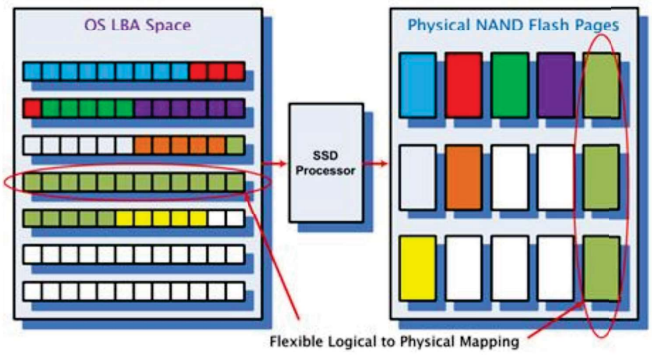
The diagram below illustrates the SSD architecture.

Why is SSD(Solid State Drive) Fast?

SSD Architecture



Mapping of Logical and Physical Pages



Step 1: “Commands come from the user through the host interface” [2]. The interface can be Serial ATA (SATA) or PCI Express (PCIe).
Step 2: “The processor in the SSD controller takes the commands and passes them to the flash controller” [2].
Step 3: “SSDs also have embedded RAM memory, generally for caching purposes and to store mapping information” [2].
Step 4: “The packages of NAND flash memory are organized in gangs, over multiple channels” [2].

The second diagram illustrates how the logical and physical pages are mapped, and why this architecture is fast.

SSD controller operates multiple FLASH particles in parallel, greatly improving the underlying bandwidth. When we need to write more than one page, the SSD controller can write them in parallel [3], whereas the HDD has a single head and it can only read from one head at a time.

Every time a HOST Page is written, the SSD controller finds a Physical Page to write the data and this mapping is recorded. With this mapping, the next time HOST reads a HOST Page, the SSD knows where to read the data from FLASH [3].

Question - What are the main differences between SSD and HDD?

If you are interested in the architecture, I recommend reading Coding for SSDs by Emmanuel Goossaert in reference [2].

Sources:
[1] SSD or HDD: Which Is Right for You?:
https://www.avg.com/en/signal/ssd-hdd-which-is-best
[2] Coding for SSDs:
https://codecapsule.com/2014/02/12/coding-for-ssds-part-1-introduction-and-table-of-contents/
[3] Overview of SSD Structure and Basic Working Principle:
https://www.elinfor.com/knowledge/overview-of-ssd-structure-and-basic-working-principle1-p-11203

Handling a large-scale outage

This is a true story about handling a large-scale outage written by Staff Engineers at Discord Sahn Lam.

About 10 years ago, I witnessed the most impactful UI bugs in my career.

It was 9PM on a Friday. I was on the team responsible for one of the largest social games at the time. It had about 30 million DAU. I just so happened to glance at the operational dashboard before shutting down for the night.

Every line on the dashboard was at zero.

At that very moment, I got a phone call from my boss. He said the entire game was down. Firefighting mode. Full on.

Everything had shut down. Every single instance on AWS was terminated. HA proxy instances, PHP web servers, MySQL databases, Memcache nodes, everything.

It took 50 people 10 hours to bring everything back up. It was quite a feat. That in itself is a story for another day.

We used a cloud management software vendor to manage our AWS deployment. This was before Infrastructure as Code was a thing. There was no Terraform. It was so early in cloud computing and we were so big that AWS required an advanced warning before we scaled up.

What had gone wrong? The software vendor had introduced a bug that week in their confirmation dialog flow. When terminating a subset of nodes in the UI, it would correctly show in the confirmation dialog box the list of nodes to be terminated, but under the hood, it terminated everything.

Shortly before 9PM that fateful evening, one of our poor SREs fulfilled our routine request and terminated an unused Memcache pool. I could only imagine the horror and the phone conversation that ensured.

What kind of code structure could allow this disastrous bug to slip through? We could only guess. We never received a full explanation.

What are some of the most impactful software bugs you encountered in your career?

AWS Lambda behind the scenes

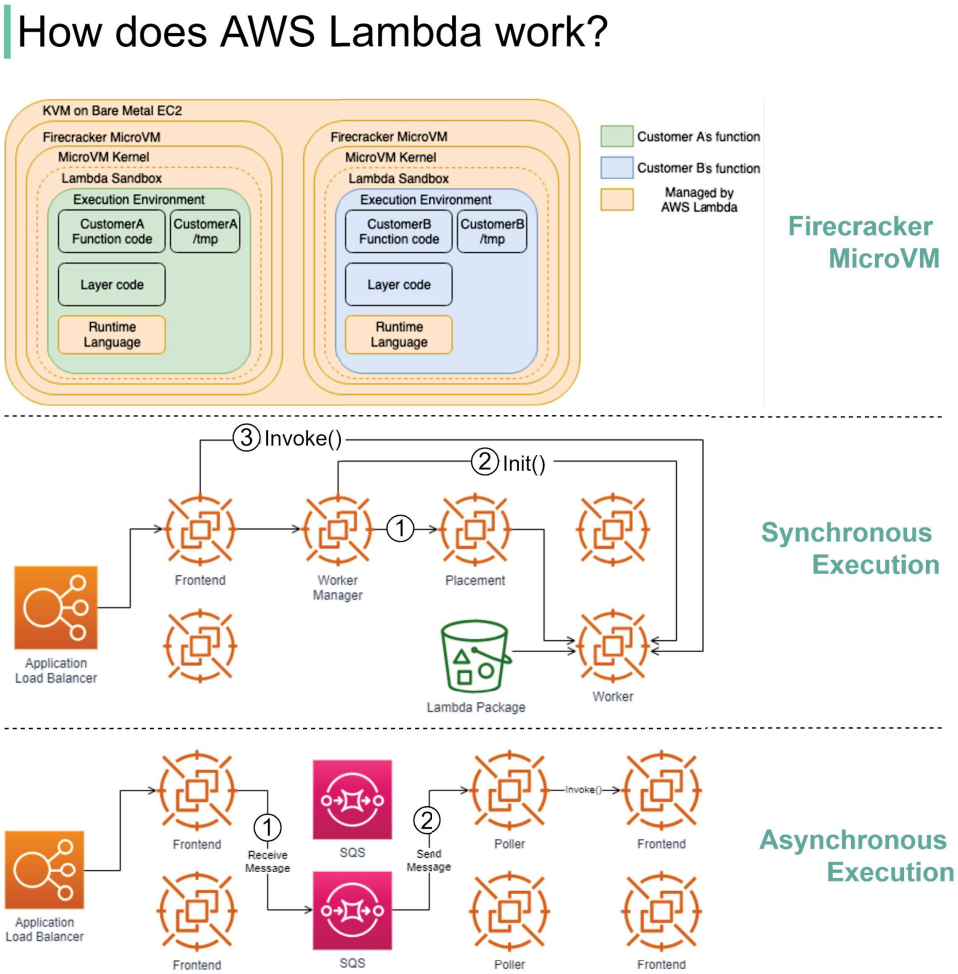
Serverless is one of the hottest topics in cloud services. How does AWS Lambda work behind the scenes?

Lambda is a **serverless** computing service provided by Amazon Web Services (AWS), which runs functions in response to events.

Firecracker MicroVM

Firecracker is the engine powering all of the Lambda functions [1]. It is a virtualization technology developed at Amazon and written in Rust.

The diagram below illustrates the isolation model for AWS Lambda Workers.



Lambda functions run within a sandbox, which provides a minimal Linux userland, some common libraries and utilities. It creates the Execution environment (worker) on EC2 instances.

How are lambdas initiated and invoked? There are two ways.

Synchronous execution
Step1: "The Worker Manager communicates with a Placement Service which is responsible to place a workload on a location for the given host (it's provisioning the sandbox) and returns that to the Worker Manager" [2].

Step 2: "The Worker Manager can then call *Init* to initialize the function for execution by downloading the Lambda package from S3 and setting up the Lambda runtime" [2]

Step 3: The Frontend Worker is now able to call *Invoke* [2].

Asynchronous execution
Step 1: The Application Load Balancer forwards the invocation to an available Frontend which places the event onto an internal queue(SQS).
Step 2: There is "a set of pollers assigned to this internal queue which are responsible for polling it and moving the event onto a Frontend synchronously. After it's been placed onto the Frontend it follows the synchronous invocation call pattern which we covered earlier" [2].

Question: Can you think of any use cases for AWS Lambda?

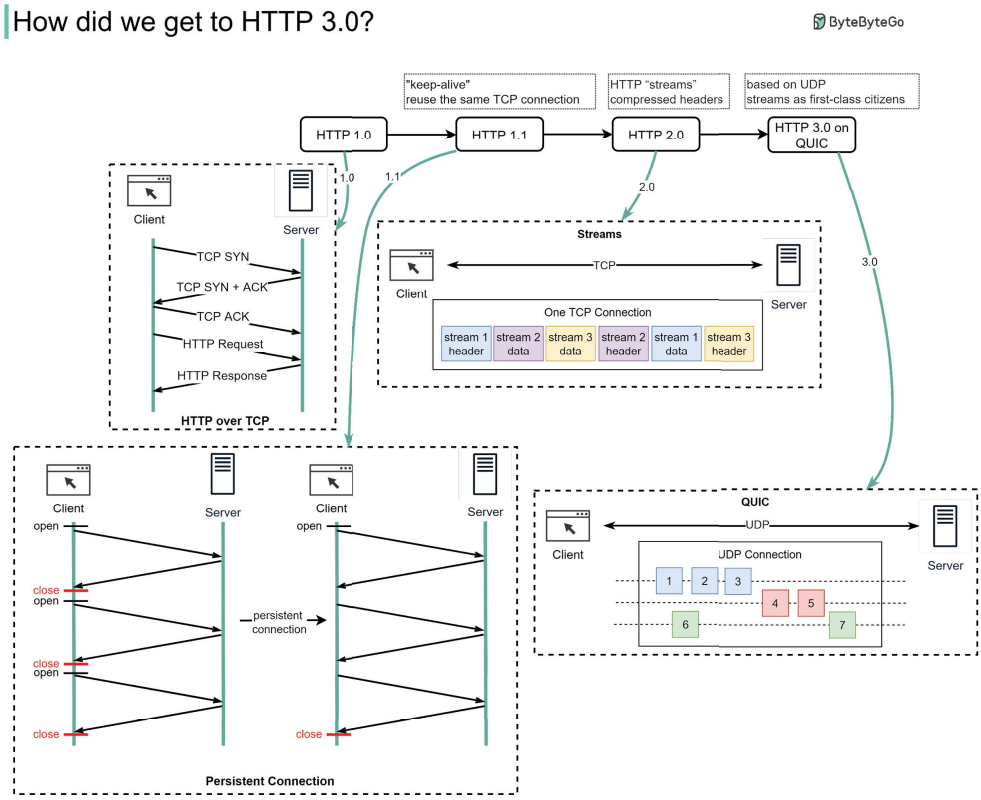
Sources:
[1] AWS Lambda whitepaper:
https://docs.aws.amazon.com/whitepapers/latest/security-overview-aws-lambda/lambda-executions.html
[2] Behind the scenes, Lambda:
https://www.bschaatsbergen.com/behind-the-scenes-lambda/

Image source: [1] [2]

HTTP 1.0 -> HTTP 1.1 -> HTTP 2.0 -> HTTP 3.0 (QUIC).

What problem does each generation of HTTP solve?

The diagram below illustrates the key features.



- HTTP 1.0 was finalized and fully documented in 1996. Every request to the same server requires a separate TCP connection.

- HTTP 1.1 was published in 1997. A TCP connection can be left open for reuse (persistent connection), but it doesn't solve the HOL (head-of-line) blocking issue.

HOL blocking - when the number of allowed parallel requests in the browser is used up, subsequent requests need to wait for the former ones to complete.

🔹 HTTP 2.0 was published in 2015. It addresses HOL issue through request multiplexing, which eliminates HOL blocking at the application layer, but HOL still exists at the transport (TCP) layer.

As you can see in the diagram, HTTP 2.0 introduced the concept of HTTP “streams”: an abstraction that allows multiplexing different HTTP exchanges onto the same TCP connection. Each stream doesn’t need to be sent in order.

🔹 HTTP 3.0 first draft was published in 2020. It is the proposed successor to HTTP 2.0. It uses QUIC instead of TCP for the underlying transport protocol, thus removing HOL blocking in the transport layer.

QUIC is based on UDP. It introduces streams as first-class citizens at the transport layer. QUIC streams share the same QUIC connection, so no additional handshakes and slow starts are required to create new ones, but QUIC streams are delivered independently such that in most cases packet loss affecting one stream doesn't affect others.

Question: When shall we upgrade to HTTP 3.0? Any pros & cons you can think of?

—

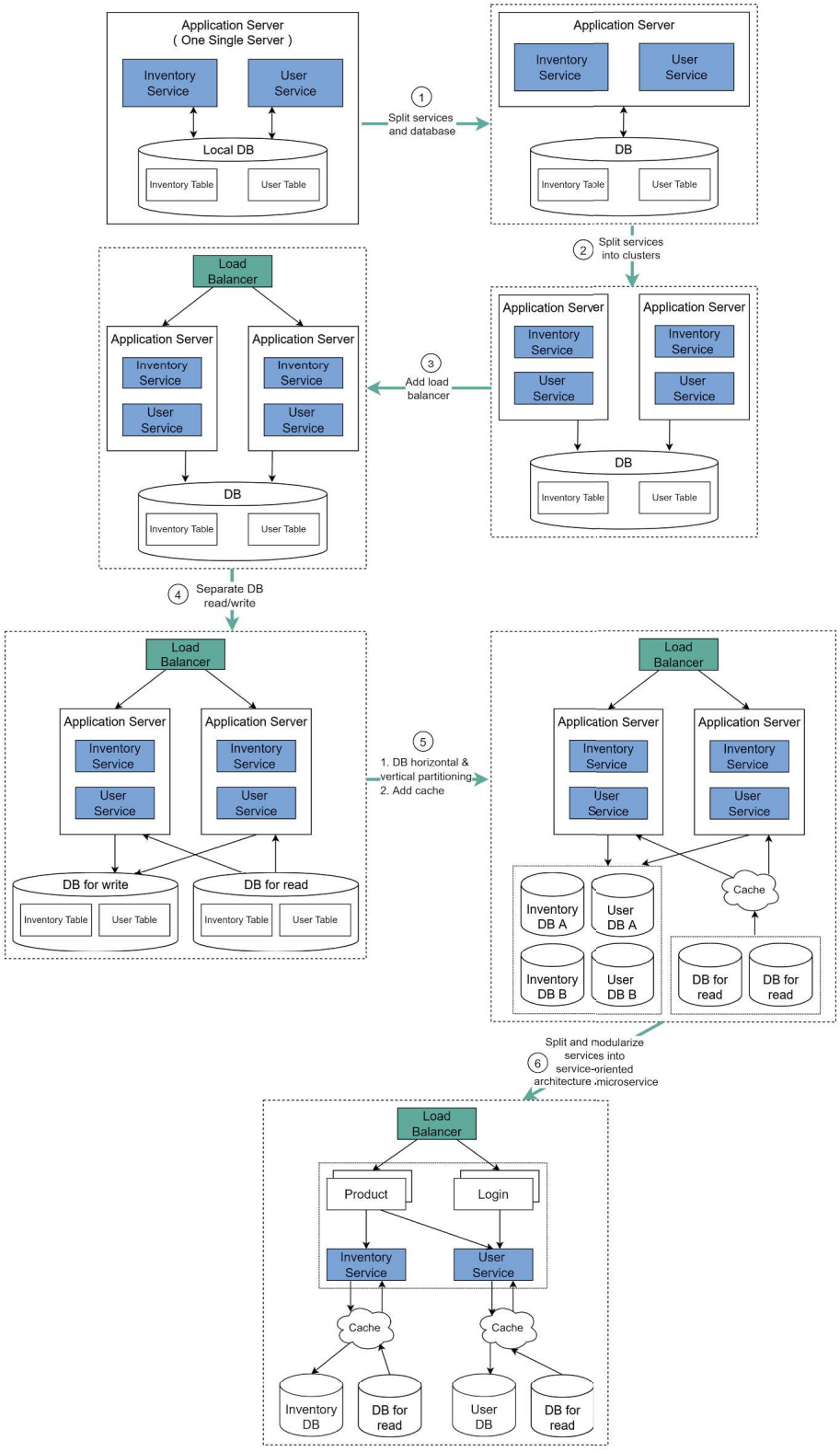
How to scale a website to support millions of users?

We will explain this step-by-step.

The diagram below illustrates the evolution of a simplified eCommerce website. It goes from a monolithic design on one single server, to a service-oriented/microservice architecture.

How to Scale a Website Step-by-Step?

ByteByteGo



Suppose we have two services: inventory service (handles product descriptions and inventory management) and user service (handles user information, registration, login, etc.).

Step 1 - With the growth of the user base, one single application server cannot handle the traffic anymore. We put the application server and the database server into two separate servers.

Step 2 - The business continues to grow, and a single application server is no longer enough. So we deploy a cluster of application servers.

Step 3 - Now the incoming requests have to be routed to multiple application servers, how can we ensure each application server gets an even load? The load balancer handles this nicely.

Step 4 - With the business continuing to grow, the database might become the bottleneck. To mitigate this, we separate reads and writes in a way that frequent read queries go to read replicas. With this setup, the throughput for the database writes can be greatly increased.

Step 5 - Suppose the business continues to grow. One single database cannot handle the load on both the inventory table and user table. We have a few options:

1. Vertical partition. Adding more power (CPU, RAM, etc.) to the database server. It has a hard limit.
2. Horizontal partition by adding more database servers.
3. Adding a caching layer to offload read requests.

Step 6 - Now we can modularize the functions into different services. The architecture becomes service-oriented / microservice.

Question: what else do we need to support an e-commerce website at Amazon's scale?

DevOps Books

Some **DevOps** books I find enlightening:

- Accelerate - presents both the findings and the science behind measuring software delivery performance.

- Continuous Delivery - introduces automated architecture management and data migration. It also pointed out key problems and optimal solutions in each area.

- Site Reliability Engineering - famous Google SRE book. It explains the whole life cycle of Google's development, deployment, and monitoring, and how to manage the world's biggest software systems.

- Effective DevOps - provides effective ways to improve team coordination.

🔹 The Phoenix Project - a classic novel about effectiveness and communications. IT work is like manufacturing plant work, and a system must be established to streamline the workflow. Very interesting read!

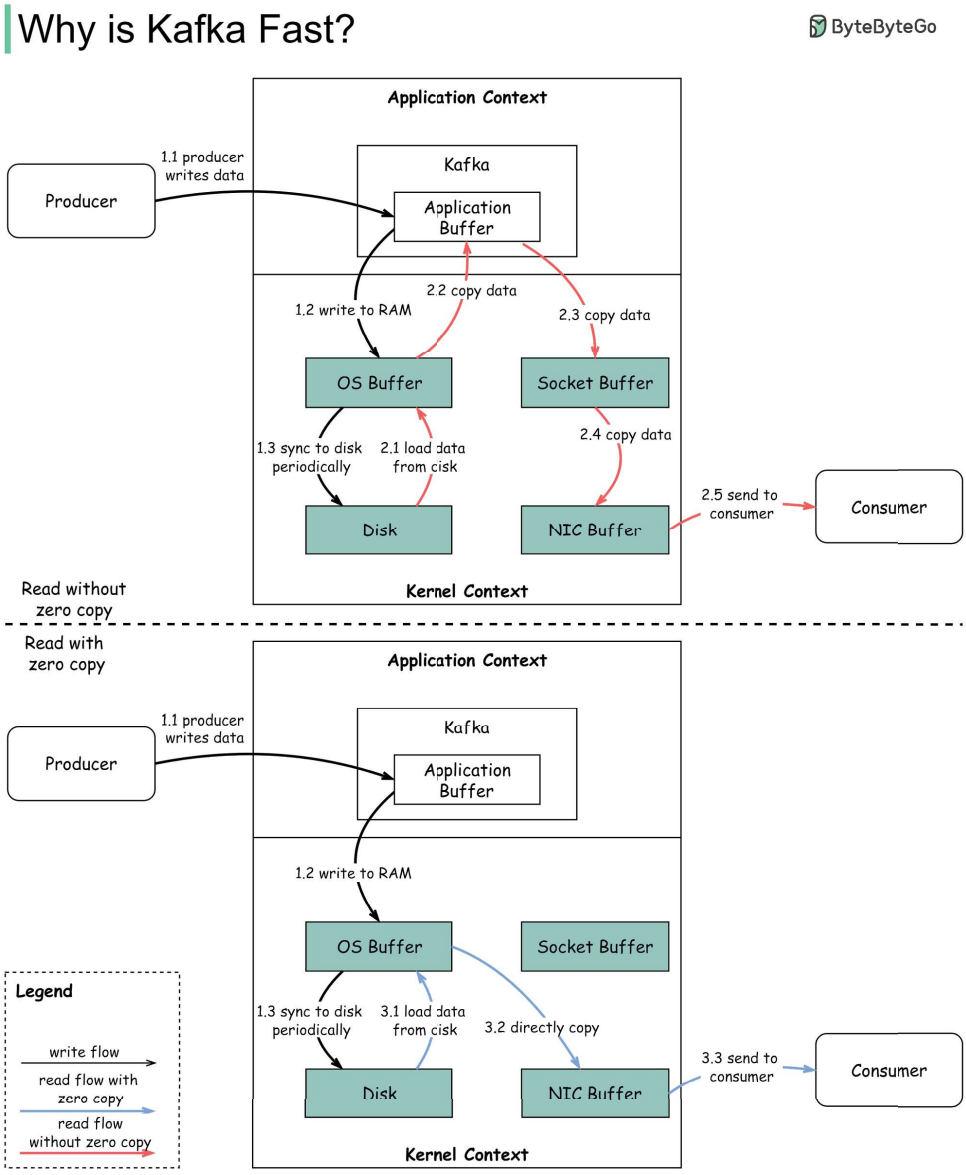
🔹 The DevOps Handbook - introduces product development, quality assurance, IT operations, and information security.

What's your favorite dev-ops book?

Why is Kafka fast?

Kafka achieves low latency message delivery through Sequential I/O and Zero Copy Principle. The same techniques are commonly used in many other messaging/streaming platforms.

The diagram below illustrates how the data is transmitted between producer and consumer, and what zero-copy means.



- Step 1.1 - 1.3: Producer writes data to the disk

🔹 Step 2: Consumer reads data without zero-copy
2.1: The data is loaded from disk to OS cache
2.2 The data is copied from OS cache to Kafka application
2.3 Kafka application copies the data into the socket buffer
2.4 The data is copied from socket buffer to network card
2.5 The network card sends data out to the consumer

🔹 Step 3: Consumer reads data with zero-copy
3.1: The data is loaded from disk to OS cache
3.2 OS cache directly copies the data to the network card via sendfile() command
3.3 The network card sends data out to the consumer

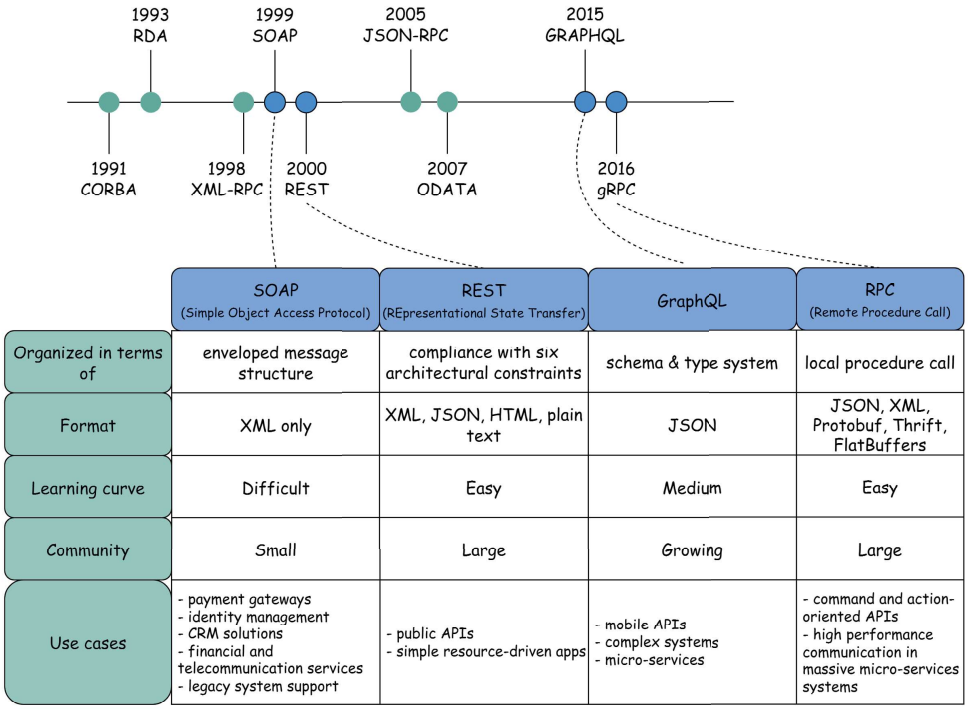
Zero copy is a shortcut to save the multiple data copies between application context and kernel context. This approach brings down the time by approximately 65%.

—

SOAP vs REST vs GraphQL vs RPC.

The diagram below illustrates the API timeline and API styles comparison.

> API Architectural Styles Comparison



	SOAP (Simple Object Access Protocol)	REST (REpresentational State Transfer)	GraphQL	RPC (Remote Procedure Call)
Organized in terms of	enveloped message structure	compliance with six architectural constraints	schema & type system	local procedure call
Format	XML only	XML, JSON, HTML, plain text	JSON	JSON, XML, Protobuf, Thrift, FlatBuffers
Learning curve	Difficult	Easy	Medium	Easy
Community	Small	Large	Growing	Large
Use cases	- payment gateways - identity management - CRM solutions - financial and telecommunication services - legacy system support	- public APIs - simple resource-driven apps	- mobile APIs - complex systems - micro-services	- command and action-oriented APIs - high performance communication in massive micro-services systems

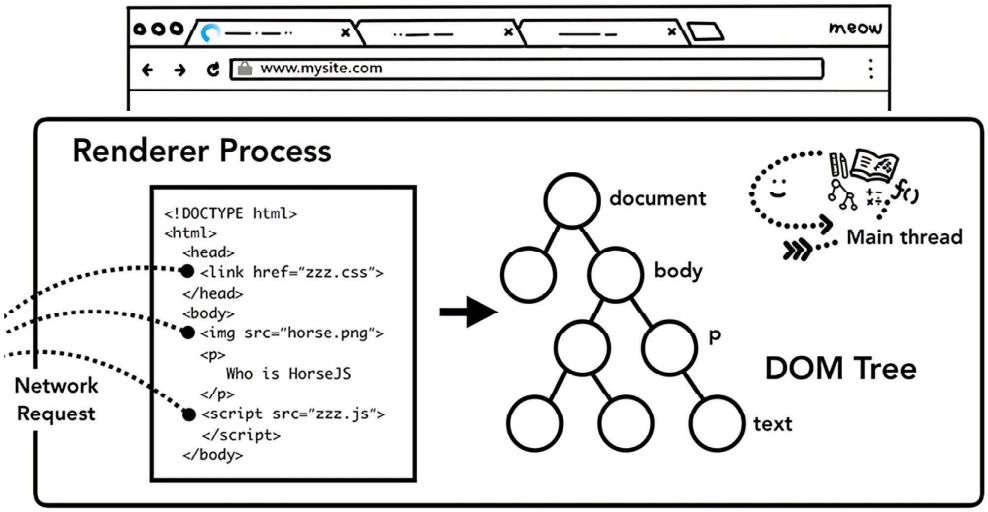
Over time, different API architectural styles are released. Each of them has its own patterns of standardizing data exchange.

You can check out the use cases of each style in the diagram.

Source: https://lnkd.in/gFgi33RY I combined a few diagrams together. The credit all goes to AltexSoft.

—

How do modern browsers work?

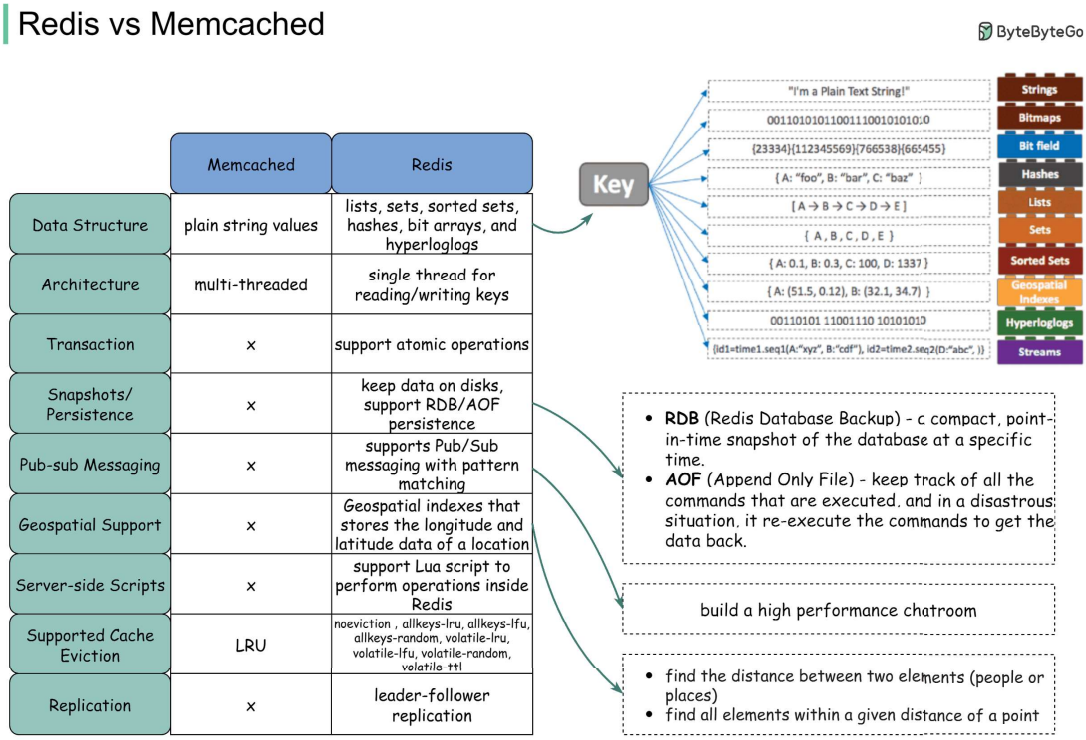


Google published a series of articles about "Inside look at modern web browser". It's a great read.

Links:
https://developer.chrome.com/blog/inside-browser-part1/
https://developer.chrome.com/blog/inside-browser-part2/
https://developer.chrome.com/blog/inside-browser-part3/
https://developer.chrome.com/blog/inside-browser-part4/

Redis vs Memcached

The diagram below illustrates the key differences.



The advantages on data structures make Redis a good choice for:

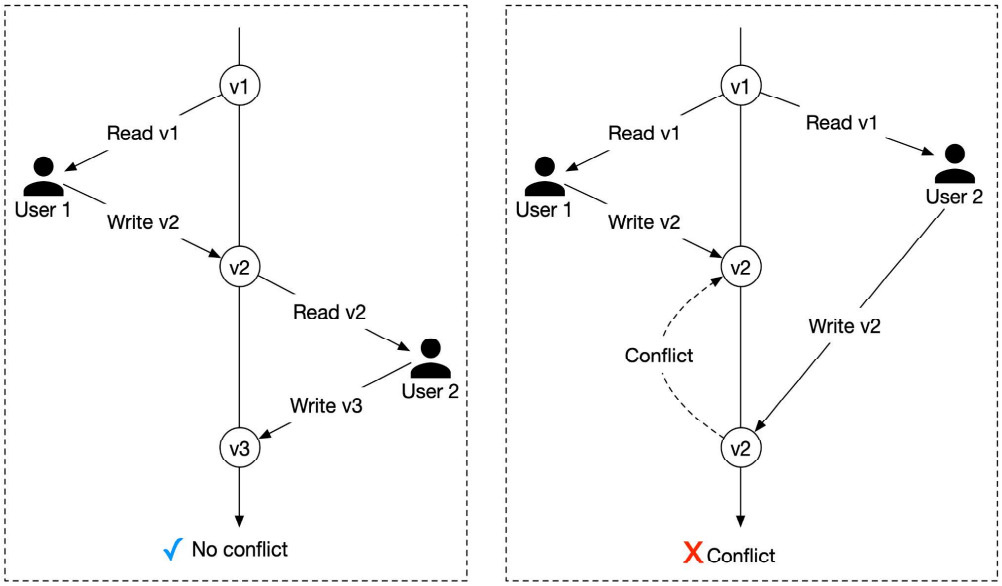
- Recording the number of clicks and comments for each post (hash)
- Sorting the commented user list and deduping the users (zset)
- Caching user behavior history and filtering malicious behaviors (zset, hash)
- Storing boolean information of extremely large data into small space. For example, login status, membership status. (bitmap)

Optimistic locking

Optimistic locking, also referred to as optimistic concurrency control, allows multiple concurrent users to attempt to update the same resource.

There are two common ways to implement optimistic locking: version number and timestamp. Version number is generally considered to be a better option because the server clock can be inaccurate over time. We explain how optimistic locking works with version number.

The diagram below shows a successful case and a failure case.



1. A new column called “version” is added to the database table.

2. Before a user modifies a database row, the application reads the version number of the row.

3. When the user updates the row, the application increases the version number by 1 and writes it back to the database.

4. A database validation check is put in place; the next version number should exceed the current version number by 1. The transaction aborts if the validation fails and the user tries again from step 2.

Optimistic locking is usually faster than pessimistic locking because we do not lock the database. However, the performance of optimistic locking drops dramatically when concurrency is high.

To understand why, consider the case when many clients try to reserve a hotel room at the same time. Because there is no limit on how many clients can read the available room count, all of them read back the same available room count and the current version number. When different clients make reservations and write back the results to the database, only one of them will succeed, and the rest of the clients receive a version check failure message. These clients have to retry. In the subsequent round of retries, there is only one successful client again, and the rest have to retry. Although the end result is correct, repeated retries cause a very unpleasant user experience.

Question: what are the possible ways of solving race conditions?

Tradeoff between latency and consistency

Understanding the **tradeoffs** is very important not only in system design interviews but also designing real-world systems. When we talk about data replication, there is a fundamental tradeoff between **latency** and **consistency**. It is illustrated by the diagram below.

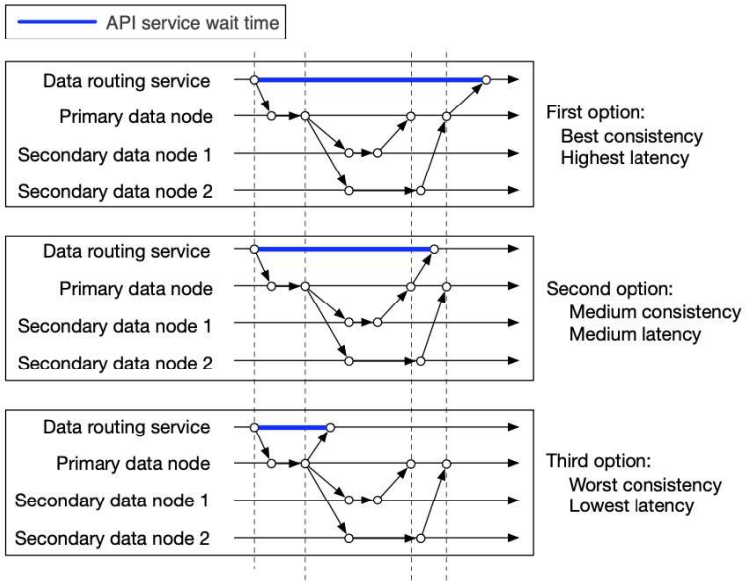


Figure 9.11: Trade-off between consistency and latency

1. Data is considered as successfully saved after all three nodes store the data. This approach has the best consistency but the highest latency.
2. Data is considered as successfully saved after the primary and one of the secondaries store the data. This approach has a medium consistency and medium latency.
3. Data is considered as successfully saved after the primary persists the data. This approach has the worst consistency but the lowest latency.

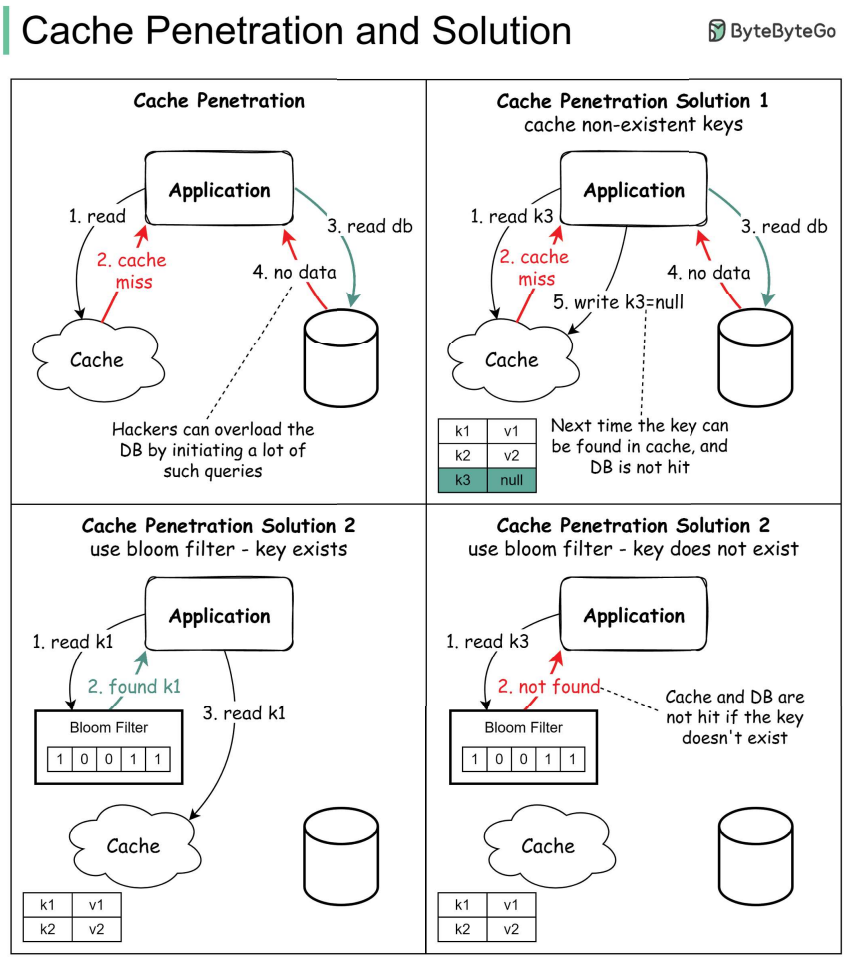
Both 2 and 3 are forms of eventual consistency.

Cache miss attack

Caching is awesome but it doesn't come without a cost, just like many things in life.

One of the issues is **Cache Miss Attack**. Correct me if this is not the right term. It refers to the scenario where data to fetch doesn't exist in the database and the data isn't cached either. So every request hits the database eventually, defeating the purpose of using a cache. If a malicious user initiates lots of queries with such keys, the database can easily be overloaded.

The diagram below illustrates the process.



Two approaches are commonly used to solve this problem:

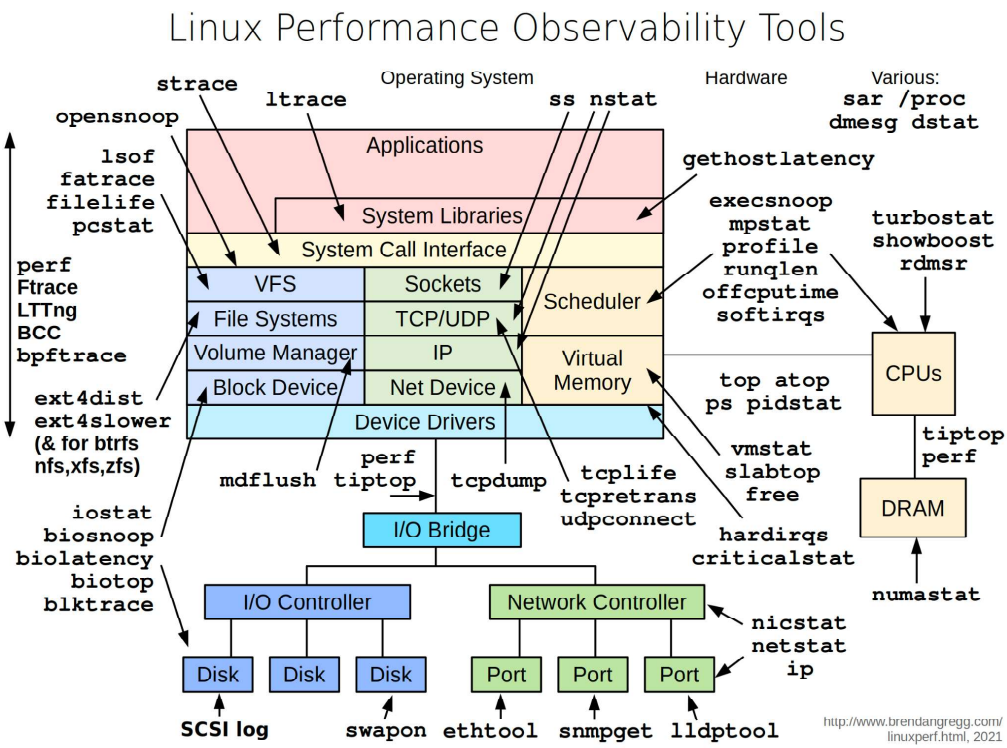
🔹 Cache keys with null value. Set a short TTL (Time to Live) for keys with null value.

🔹 Using Bloom filter. A Bloom filter is a data structure that can rapidly tell us whether an element is present in a set or not. If the key exists, the request first goes to the cache and then queries the database if needed. If the key doesn't exist in the data set, it means the key doesn’t exist in the cache/database. In this case, the query will not hit the cache or database layer.

—

How to diagnose a mysterious process that's taking too much CPU, memory, IO, etc?

The diagram below illustrates helpful tools in a Linux system.



- 'vmstat' - reports information about processes, memory, paging, block IO, traps, and CPU activity.

- 'iostat' - reports CPU and input/output statistics of the system.

- 'netstat' - displays statistical data related to IP, TCP, UDP, and ICMP protocols.

- 'lsof' - lists open files of the current system.

- 'pidstat' - monitors the utilization of system resources by all or specified processes, including CPU, memory, device IO, task switching, threads, etc.

What are the top cache strategies?

Read data from the system:

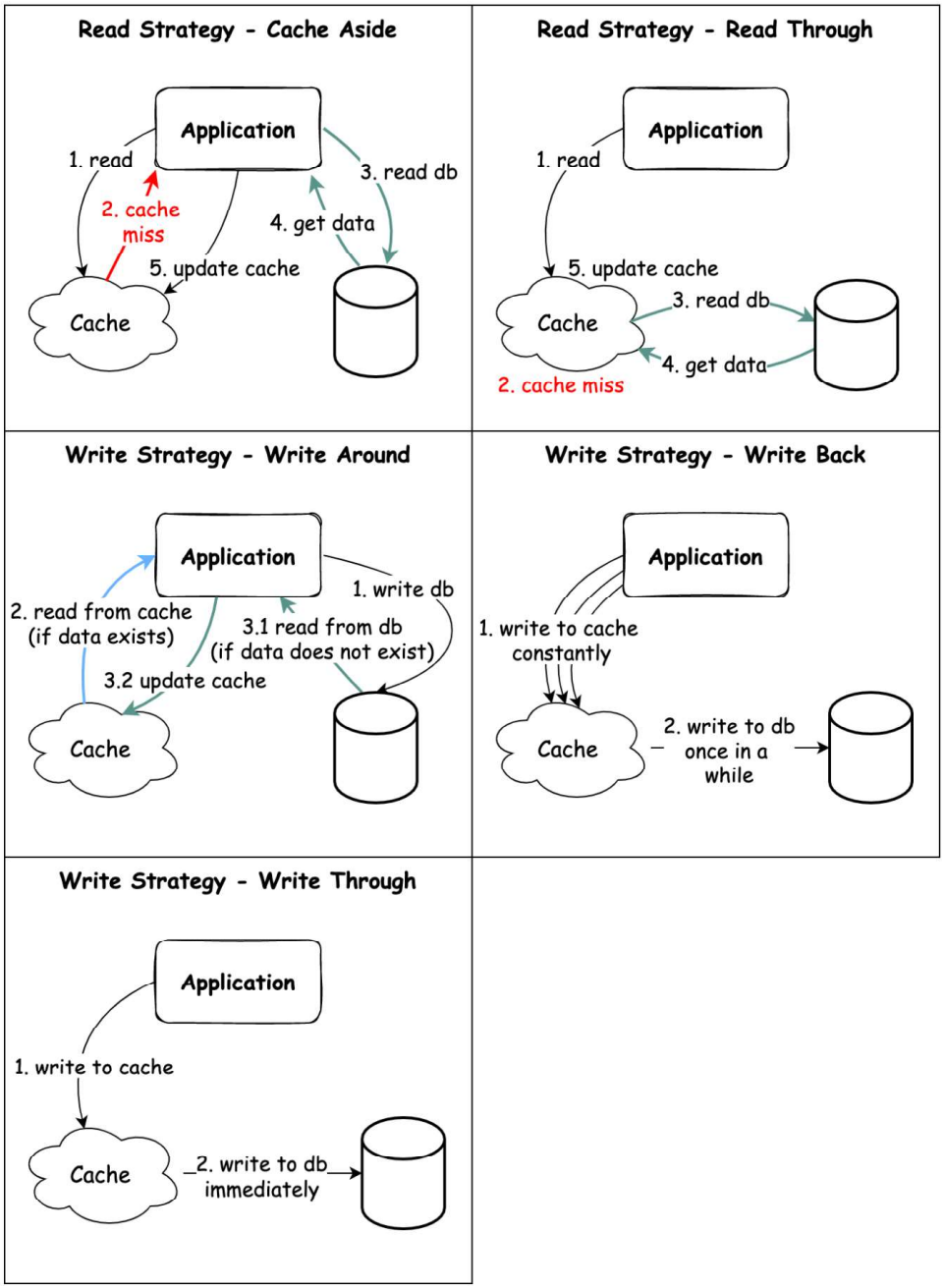
- Cache aside
- Read through

Write data to the system:

- Write around
- Write back
- Write through

The diagram below illustrates how those 5 strategies work. Some of the caching strategies can be used together.

Top caching strategies



I left out a lot of details as that will make the post very long. Feel free to leave a comment so we can learn from each other.

Question: What are the pros and cons of each caching strategy? How to choose the right one to use?

—

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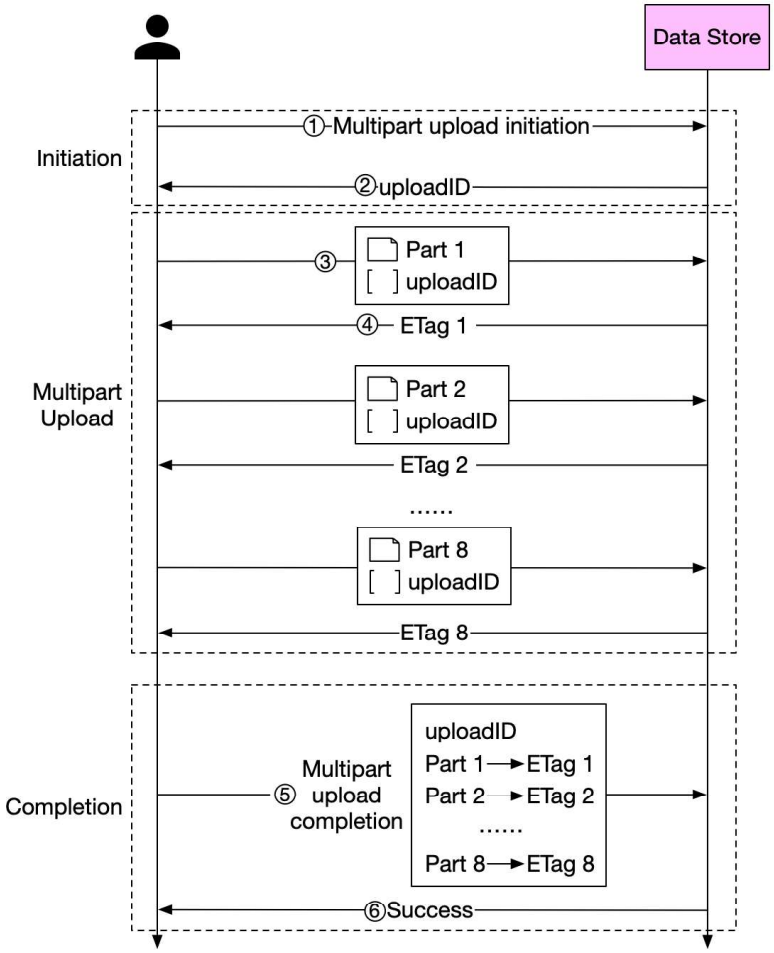
Upload large files

How can we optimize performance when we **upload large files** to object storage service such as S3?

Before we answer this question, let's take a look at why we need to optimize this process. Some files might be larger than a few GBs. It is possible to upload such a large object file directly, but it could take a long time. If the network connection fails in the middle of the upload, we have to start over. A better solution is to slice a large object into smaller parts and upload them independently. After all the parts are uploaded, the object store re-assembles the object from the parts. This process is called **multipart upload.**

The diagram below illustrates how multipart upload works:



1. The client calls the object storage to initiate a multipart upload.

2. The data store returns an uploadID, which uniquely identifies the upload.

3. The client splits the large file into small objects and starts uploading. Let's assume the size of the file is 1.6GB and the client splits it into 8 parts, so each part is 200 MB in size. The client uploads the first part to the data store together with the uploadID it received in step 2.

4. When a part is uploaded, the data store returns an ETag, which is essentially the md5 checksum of that part. It is used to verify multipart uploads.

5. After all parts are uploaded, the client sends a complete multipart upload request, which includes the uploadID, part numbers, and ETags.

6. The data store reassembles the object from its parts based on the part number. Since the object is really large, this process may take a few minutes. After reassembly is complete, it returns a success message to the client.

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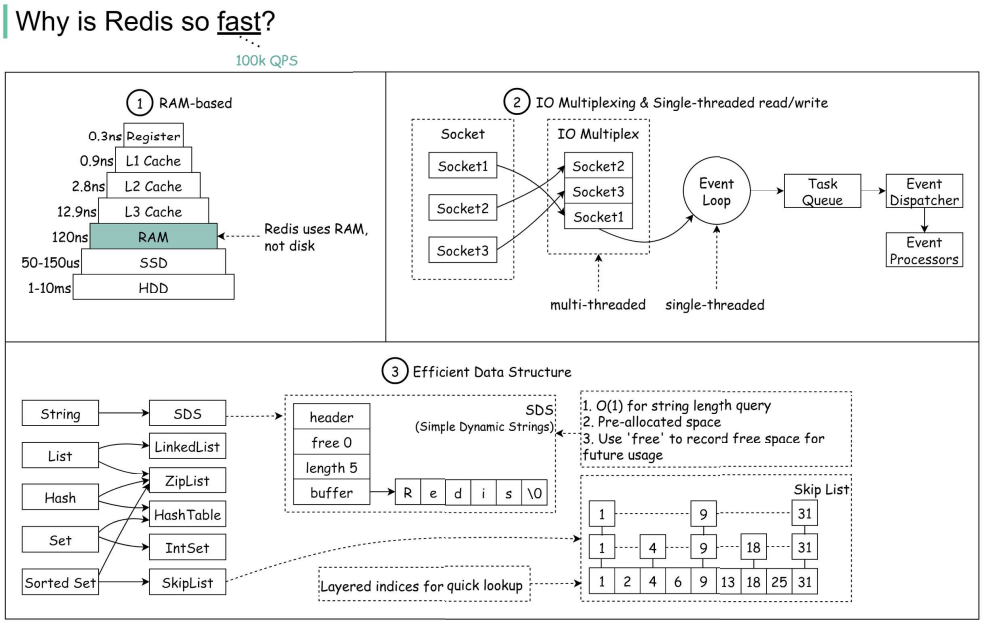
Why is Redis so Fast?

There are 3 main reasons as shown in the diagram below.



1. Redis is a RAM-based database. RAM access is at least 1000 times faster than random disk access.

2. Redis leverages IO multiplexing and single-threaded execution loop for execution efficiency.

3. Redis leverages several efficient lower-level data structures.

Question: Another popular in-memory store is Memcached. Do you know the differences between Redis and Memcached?

You might have noticed the style of this diagram is different from my previous posts. Please let me know which one you prefer.

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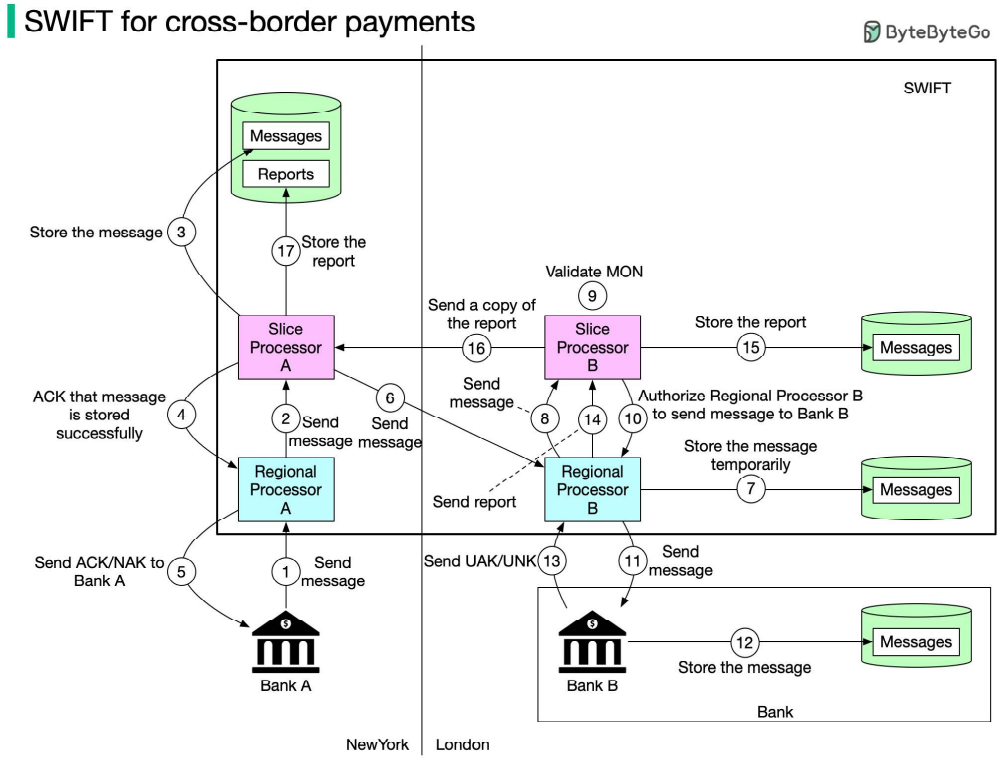
SWIFT payment network

You probably heard about **SWIFT**. What is SWIFT? What role does it play in cross-border payments? You can find answers to those questions in this post.



The Society for Worldwide Interbank Financial Telecommunication (SWIFT) is the main secure **messaging system** that links the world's banks.

The Belgium-based system is run by its member banks and handles millions of payment messages per day. The diagram below illustrates how payment messages are transmitted from Bank A (in New York) to Bank B (in London).

Step 1: Bank A sends a message with transfer details to Regional Processor A in New York. The destination is Bank B.

Step 2: Regional processor validates the format and sends it to Slice Processor A. The Regional Processor is responsible for input message validation and output message queuing. The Slice Processor is responsible for storing and routing messages safely.

Step 3: Slice Processor A stores the message.

Step 4: Slice Processor A informs Regional Processor A the message is stored.

Step 5: Regional Processor A sends ACK/NAK to Bank A. ACK means a message will be sent to Bank B. NAK means the message will NOT be sent to Bank B.

Step 6: Slice Processor A sends the message to Regional Processor B in London.

Step 7: Regional Processor B stores the message temporarily.

Step 8: Regional Processor B assigns a unique ID MON (Message Output Number) to the message and sends it to Slice Processor B

Step 9: Slice Processor B validates MON.

Step 10: Slice Processor B authorizes Regional Processor B to send the message to Bank B.

Step 11: Regional Processor B sends the message to Bank B.

Step 12: Bank B receives the message and stores it.

Step 13: Bank B sends UAK/UNK to Regional Processor B. UAK (user positive acknowledgment) means Bank B received the message without error; UNK (user negative acknowledgment) means Bank B received checksum failure.

Step 14: Regional Processor B creates a report based on Bank B's response, and sends it to Slice Processor B.

Step 15: Slice Processor B stores the report.

Step 16 - 17: Slice Processor B sends a copy of the report to Slice Processor A. Slice Processor A stores the report.

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